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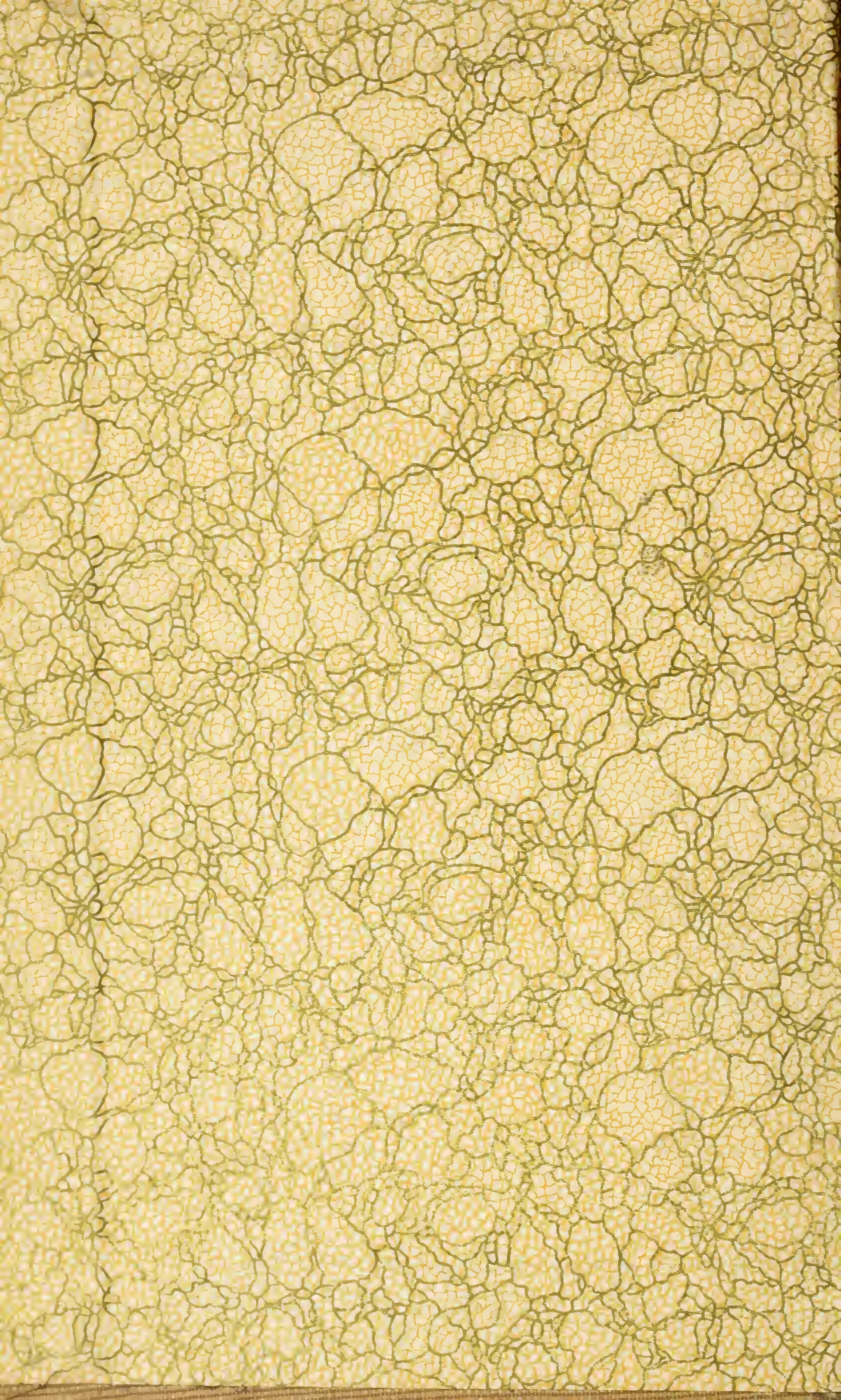

U. S. DEPARTMENT OF AGRICULTURE.
BUREAU OF PLANT INDUSTRY—BULLETIN NO. 192.
B. T. GALLOWAY, *Chief of Bureau.*

DROUGHT RESISTANCE OF THE OLIVE IN THE SOUTHWESTERN STATES.

BY

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BREEDING INVESTIGATIONS.

ISSUED JANUARY 17, 1911.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1911.

BUREAU OF PLANT INDUSTRY.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Plant Industry,
Office of the Chief,
Washington, D. C., July 30, 1910.

Sir: I have the honor to transmit herewith and to recommend for publication as Bulletin No. 192 of the special series of this Bureau the accompanying manuscript, entitled "Drought Resistance of the Olive in the Southwestern States." This paper was prepared by Prof. Silas C. Mason, Arboriculturist in Crop Physiology and Breeding Investigations, and has been submitted by Mr. Walter T. Swingle, Physiologist in Charge, with a view to its publication.

The data upon which the paper is based were obtained from the study of olive plantations made in Arizona and California, started under irrigation, but afterwards, through the failure of the water supply, left to their fate.

While most fruit trees and vines planted under similar conditions soon perished, the olive trees have survived and made considerable growth, showing themselves to be true desert plants having marked drought-resistant characters.

So strong is this characteristic in the case of some of the varieties of olives grown for oil that it is considered desirable to investigate the possibility of olive culture for oil production in those areas in the Southwest having favorable conditions as to temperature and soil, but with a rainfall not heretofore believed to be sufficient for crop production. At the same time those who desire to experiment should be warned not to plant extensively until the possibilities of fruit production in any particular region have been thoroughly investigated.

With the enactment and enforcement of the Pure Food Law the production of olive oil in the Western States is now on a much different footing from that of a few years ago. Where large quantities of cheap adulterants and substitutes were then sold as pure olive oil, now the olive grower has a market for his product on its merits. With the better prices now prevailing, there seems to be encouragement for a considerable extension of the oil-olive industry.

Mr. Thomas H. Kearney has published a bulletin in this series, entitled "Dry-Land Olive Culture in Northern Africa," describing the methods pursued in dry-land olive culture in southern Tunis, methods which are now being tested in this country by Prof. S. C. Mason and Mr. Kearney in cooperation.

Respectfully,

G. H. Powell,
Acting Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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DROUGHT RESISTANCE OF THE OLIVE IN THE SOUTHWESTERN STATES.

INTRODUCTION.

Olive culture in the United States has passed through many vicissitudes. Hence, for the fullest knowledge of this industry to-day we should study not only those cases where olive planting has been a financial success, but the frequent instances where a more or less successful growth of olive trees has been obtained without a remunerative production of fruit. The olive tree may maintain life and even make considerable growth under conditions of drought and heat so severe that only the most hardy types of desert trees are able to survive them, yet the margin between such a purely vegetative growth and the production of fruit in remunerative quantities may be a very wide one, so wide that to invest money in the planting and care of olive trees on a commercial scale under such conditions would be sheer folly.

Again, it may occur that one olive grove is producing bountifully while another near by, under substantially the same conditions as to temperature, rainfall, and soil may give but a scant return. Here the choice of varieties, the distance of planting, and the methods of culture and pruning, factors all within the control of the grower, may be quite sufficient to explain the difference between success and failure.

In fact with any given example of olive trees which do not fruit, especially if they are distant from productive trees for comparison, only the closest study and thorough experimentation can determine how narrow the margin may be between their present conditions and those of profitable fruit production.

When any plant of economic value is found to possess great ability to resist drought or heat that fact in itself becomes a matter worth close investigation. How does it obtain its supply of moisture? By means of deeply penetrating roots or of superficial roots exploring great areas? Has it some provision for the storage of moisture in time of surplus? Does it possess peculiarities of stem or leaf structure by which the small moisture supply is conserved to the utmost and the living cells insulated and protected in the most effective manner against the desiccating effects of dry air and intense heat? We may even inquire whether its cycle of growth in relation to the seasons does not undergo an adjustment adapting itself to periods of drought and rainfall.

The present bulletin is an attempt to answer such questions in relation to the olive, and the material upon which it is based has been furnished by a number of plantations of olives made in the more arid parts of Arizona and California, where through failure of the irrigation systems the trees were thrown on their own resources. It is noteworthy that in all such cases where besides olives other fruit trees were planted, few of the olives died and almost without exception all other fruit trees perished.

DRY-LAND OLIVE INVESTIGATIONS.

In the writer's study of the possibilities in dry-land tree growth in southern Arizona and southern California his attention has been called to several cases of abandoned plantations where, along with other fruit and ornamental trees, considerable blocks of olives had been planted. With the failure of the irrigation canals and the consequent cessation of care and culture of the trees, almost all kinds died.

The survival of the olives, and not only their survival but continued growth and luxuriant appearance, was so notable a feature as to attract the attention of observing ranchmen of the vicinity, for it must be kept in mind that these were localities where irrigation was not simply a convenience, but an absolute necessity to the growing of every crop at present known to them.

The examples given below showing not the results of careful test and experimentation but results obtained unwittingly and in the face of disaster seem worthy of careful record when studied in the light of the remarkable dry-land olive culture in Tunis, for the first time brought to the attention of this country by Mr. Thomas H. Kearney,[a] of the Bureau of Plant Industry.

EXAMPLES OF DROUGHT RESISTANCE OF THE OLIVE IN THE UNITED STATES.

AN ABANDONED OLIVE GROVE AT CASA GRANDE, ARIZ.

The first of the abandoned plantations noted was that known as the Bogart-Degolia ranch, 2 miles south of Casa Grande station in Pinal County, Ariz. (See fig. 1.) The altitude of the station is about 1,396 feet, and the olive orchard is only a few feet higher. The mean annual temperature for the twenty-three years recorded is 72° F., and the average annual rainfall is 6.88 inches.

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[a] See "Dry-land Olive Culture in Northern Africa," Bulletin 125, Bureau of Plant Industry, U. S. Dept. of Agriculture, 1908.

TABLE I.—*Average rainfall by months and annual average for Casa Grande, Phoenix, Maricopa, and Mesa, Ariz., for the years from 1897 to 1908, inclusive.*[a]

Station.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
	In.	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*
Casa Grande	[b]1.04	0.86	[b]0.36	0.25	0.03	[b]0.19	[b]0.97	1.03	[b]0.37	[b]0.13	0.88	0.78	[b]6.88
Phoenix	1.10	.90	.51	.51	.05	.11	1.03	.98	.98	.32	.89	.72	8.11
Maricopa	.78	.72	.38	.33	.04	.16	.91	.83	.52	.25	.72	.78	6.41
Mesa	1.11	1.02	.80	.49	.08	.12	.83	1.31	.59	.35	.861	.01	8.60
Average	1.01	0.87	0.51	0.39	0.05	0.14	0.93	1.04	0.62	0.26	0.84	0.82	7.52

[a] The figures of this table were kindly furnished by Mr. L. N. Jesunofsky, section director, Weather Bureau, Phoenix, Ariz.

[b] These means were obtained by substituting the mean of the month specified in places where the record was wanting.

Figure 2 shows graphically the average rainfall by months for Casa Grande, Ariz., and adjacent stations, from 1897 to 1908, inclusive. The two periods of greater rainfall each year, one culminating in August and one in November, with May and June nearly rainless, are characteristic of the region.

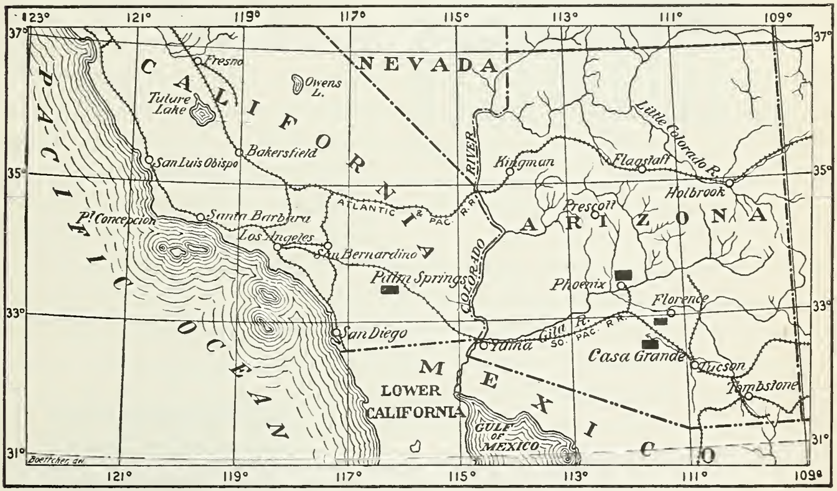

FIG. 1.—Map showing the points in Arizona and southern California where dry-land olive growth was studied.

The range of temperature during the year is from a minimum of 25° or 28° F., with occasional years as low as 17°, to a maximum of 117° to 122° F. The mean relative humidity recorded for Phoenix in Table II and graphically illustrated in figure 3 will not be far from correct for the Casa Grande region.

TABLE II.—*Mean monthly and mean annual relative humidity of Phoenix, Ariz., for the years 1905, 1906, and 1907.*

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
1905	61	71	67	58	35	25	29	42	41	40	65	59	49
1906	50	60	48	40	31	20	34	47	30	31	45	65	42
1907	66	58	51	30	28	24	36	44	36	55	55	42	44

The country around Casa Grande is a wide plain, through the level of which the mountains appear to be thrust up, so abruptly do the scattering groups and single low peaks break the surface. These mountains are largely composed of a soft, rapidly disintegrating granite, with much feldspar in its composition, and their decay determines the character of the soil, which is coarse and gravelly around the mountain base, sandy with more of clay a little farther away, and of a stiff clay nature mingled with bars of sand and gravel along the drainage courses, scarcely as yet marked as stream channels, which serve to carry away the run-off from the occasional torrential rains so characteristic of the region.

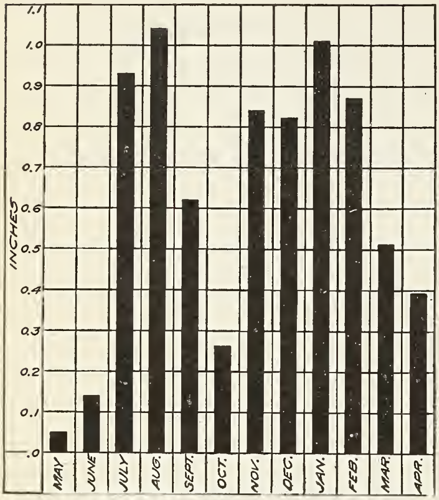

FIG. 2.—Diagram showing the mean monthly rainfall at Casa Grande, Maricopa, Phoenix, and Mesa, Ariz., as presented in Table I.

The most important of these water courses, sometimes dignified on the maps by being called the Santa Cruz River, is locally given the more appropriate name "Santa Cruz Wash." While along its upper course, from the Mexican boundary down to Tucson, there is a pretty well-marked channel and a more or less continuous flow of water, in the neighborhood of Casa Grande a slightly cut channel, a broad, well-marked flood area, and a still broader belt of mesquite growth mark the course of the so-called river.

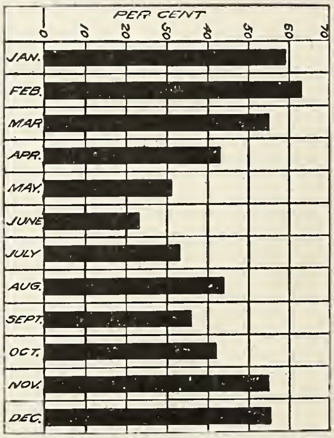

FIG. 3.—Diagram showing the mean monthly relative humidity at Phoenix, Ariz., as presented in Table II.

The popular idea that there is a strong underflow of water the entire length of this valley is given support by the heavy belt of mesquite which occurs with more or less regularity along the course. This tree is well known throughout the desert regions of the Southwest as possessing a remarkable root system, able to penetrate to water-bearing strata at depths of 30 to 50 feet. The further fact that the railroad wells along the line of the Southern Pacific Company, particularly those at Maricopa and Casa Grande, 2 or 3 miles away from the main channel, afford an abundant flow of water from deep borings, in which the water rises to within 40 to 50 feet of the surface, seems to confirm the impression.

The ranch of which the olive orchard forms a part lies fully 3 miles south of the main Santa Cruz channel, with a gentle slope toward it. A heavy mesquite growth had first to be removed as a preparation for planting, and much growth of the same nature is still to be found adjacent, indicating the presence of a water supply at a depth of 30 to 50 feet. The soil contains a large percentage of coarse granitic sand, but with enough clay to give it considerable body and cause it to bake when dry. (See Tables IV and V.)

THE BOGART-DEGOLIA OLIVE GROVE.

According to the best testimony available, the Bogart-Degolia ranch was planted in 1893. It was at the time of the highest prosperity of the so-called Florence canal, which took water from the Gila River near the town of Florence. About 20 acres of the ranch were set to Muscat and Thompson seedless grapes, figs, apricots, prunes, and olives, there being perhaps 5 acres of olives. The supply of water, while never abundant, was adequate for several years, and the enterprise gave every promise of success.

Owing to the partial failure of the water for the past seven or eight years, the trees have had no water save the rainfall and a little local run-off that the otherwise dry ditches carried to the orchard.

We have no record of the exact order in which the trees began to perish. When examined in March, 1907, all the trees planted were dead except the olives, a few Arizona ash (*Fraxinus velutina*) which had been set along the main ditch where they could profit by the run-off which it could collect, and a few fig trees which still sent feeble sprouts from the base. Appearances would indicate, however, that the apricots and prunes were the first to succumb, followed by the figs.

After the place was deserted, cattle and horses dependent on the scanty desert herbage broke into the inclosure and attacked the olive trees, browsing off all of the tender growth within reach. This fact in itself bears testimony to the scantiness of forage on this plain, for of all the forms of vegetation brought forward as forage plants the olive has not so far been considered in the United States.[a] Many of these trees were browsed and broken till mere prongs and stubs, 3 or 4 feet high, were all that was left of them. None of the trees seem to have been pruned from the first, and the greater number of them had formed several divergent stems from the ground. It was usually where the outer stems had formed a sufficient barrier against the stock that the central ones had attained an adequate growth to enable them to resist attack. Many of these have reached a height of 12 to 15 feet, and a few exceptionally strong specimens are 18 to 20 feet high. (See Pl. I, fig. 1.)

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[a] Mr. Thomas H. Kearney states that during dry years in Algeria branches cut from olive trees are a regular forage supply. See Bulletin 80, Bureau of Plant Industry, U. S. Dept. of Agriculture, p. 80.

The foliage is a dark, luxuriant green, and vigorous new growth is being made, even on those trees that have been most severely cropped back by cattle. The whole plantation is a notable landmark on the desert plain and can be seen for a long distance. In fact, uncultivated and abandoned to struggle for itself, the olive has made a winning fight in fair competition with the mesquite of the surrounding desert, even though it has lacked the thorny defense against grazing animals which nature has supplied to the desert tree.

The uniform distance in setting out this entire plantation was in squares 24 feet apart. This would prove to be rather too close planting even in an orchard having an abundant supply of water, but where the supply is as scant as this plain affords experience has shown that this spacing, which provides for 75 trees to the acre, is much too close. The luxuriant growth of a portion of these trees was doubtless made possible by the weakened competition of those closely cropped by stock. The olive tree has the ability to produce a system of shallow roots, fully occupying the ground for a wide radius around each tree. But a few years are needed for a tree to completely take possession of the soil over a radius of 12 feet, after which the struggle must begin with neighboring trees for the available moisture.

A detailed study of the roots of a typical tree was made—a tree with a trunk diameter of only 5 inches, enlarged just below the surface of the ground into a burl 12 inches in diameter and 14 inches in depth, from which radiated 12 roots from a half inch to 2 inches in diameter. Some of these roots had a length of 12 to 14 feet. So numerous were the branches and small feeding rootlets originating from these roots that the soil from a depth of 2 or 3 inches to more than a foot was filled with them.

The description of "Olive root systems" in this bulletin will afford details applicable to all of these plantations.

At the remote areas penetrated by branches from the large roots the ground was contested by feeding roots from the adjacent trees, so that it was hardly possible to turn up a shovelful of earth in the orchard without finding evidence of this reaching out for moisture. Yet there was no taproot and no penetrating to great depths for water, as is so characteristic of the mesquite, which had been the natural occupant of this land. It was a most complete and perfect system for appropriating the moisture in the first 15 or 18 inches of the soil, just that which would be penetrated by the normal rainfall.

The soil, greatly deficient in humus, contains clay enough to make it very hard when dry, and the tramping of grazing stock still further compacted the surface, preventing the ready absorbing of water when a rainfall came. Application of the now well-known principles of thorough cultivation and light furrowing across the slope to secure water storage and the retarding of evaporation by a dust mulch would have aided these trees greatly in utilizing the rain which fell.

DRY-LAND OLIVE GROVE NEAR FLORENCE, ARIZ.

Not far from the Casa Grande and Florence road, in the valley of the Gila River and about 5 miles southwest of Florence (see map, fig. 1), a ranch was developed and a plantation of olives and other fruits was made, probably at about the same time as that at Casa Grande. An area of about 8 acres was set in olives, the trees being arranged in squares 20 feet apart each way. This tract has been kept securely fenced, so that no damage from live stock has occurred. From the scant information that can be gathered these trees have received no irrigation for six years.

The soil is a much stiffer clay than that at Casa Grande. A well near the orchard, now caved in, shows no water for a depth of more than 40 feet. An inspection of this grove shows that while possibly 5 per cent of the original setting of trees failed to grow, but a very few died later. The average height of these trees is about 20 feet. A majority of them grow in the form of stools, sending out several minor stems from near the ground. Some single trunks from 8 to 12 inches in diameter were noted. The formation of a much enlarged burl at the surface of the ground was a very common feature.

A most significant fact was that the trees around the borders of the grove were much larger and of more vigorous and healthy growth than those where there was a perfect stand in the interior. While few of the interior trees are dying, the scantier and less healthy foliage and more slender growth of the branches all testify to the severity of the struggle for moisture which is taking place. (See Pl. II, fig. 2.)

No systematic study of the root development was made, but a number of holes dug in various parts of the grove showed that, as in the Casa Grande grove, the extent of roots was such as to occupy the entire area, fine rootlets being disclosed wherever the soil was turned. Even where missing trees gave a diagonal distance of more than 45 feet between those standing, the roots had extended so as to occupy this space.

A most significant fact concerning this planting is shown in Plate II, from photographs taken in March, 1909. A block of about 3 acres of apricots and almonds planted by the side of the olives is shown in Plate II, figure 1, on the left. The trees had made an excellent growth, but with the failure of the water every one of them has died. On the right are seen the olive trees still making a good growth. A few pomegranate bushes and pepper trees planted in the dooryard adjacent to the olives, while nearly all living, have apparently suffered more seriously from drought than the olives.

DRY-LAND OLIVE TREES NEAR PHOENIX, ARIZ.[a]

A few miles northeast of Phoenix, Ariz., a tract of land was laid off into a sort of residence park under the name of "Las Palmas."[b] Numerous avenues and drives were planted with Canary Island palms, pepper trees, and other ornamentals, and at the same time a considerable number of olive trees was set out, a row along the south side of the southeast quarter being half a mile long. Owing to difficulties about the water supply, cultivation and care ceased over all but a small part of the tract, so that for the past six years no irrigation has been given the olives and peppers on the south side of the section and only a small amount to some of the palms.

The soil here, though gravelly, is much richer in clay and fine silt than that of the Casa Grande tract. This portion of section 22 has for several years been heavily pastured by horses, cattle, and sheep, the trampling of this stock being sufficient to render the ground around the row of olives smooth and compact, so that much of the rainfall would be turned off instead of being caught and allowed to percolate to the roots. A much better supply of forage seems to have prevented the stock in this pasture from browsing the olives as severely as was done at Casa Grande, though apparently sheep have fed off the leaves and small twigs to a height of about 4 feet.

We find this to be a case of growth under decidedly adverse conditions, though not the most extreme. The row of olive trees along the south side of the section is uneven in growth, but many are 12 to 15 feet high, with trunks from 5 to 7 inches in diameter. Here, as in other droughty situations, the olive has a strong tendency to put out sprouts from near the base, thus protecting the trunk from the heat of the sun. This universal habit of olive trees in dry localities, even those that have been headed high enough to expose the trunk, points clearly to the desirability of a method of pruning which will provide a low, spreading head, thoroughly protecting the trunk and main branches.

That several of the trees in this south row should have fruited in 1907 in the face of such privation and neglect, though producing only a light crop, is strong evidence of the hardiness and drought resistance of the olive.

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[a] See map, figure 1.

[b] Comprising section 22, in township 2 north, range 3 east.

In the northern portion of the ranch olive trees which had received a little irrigation and less trampling and hardening of the ground produced fair crops of fruit, thus demonstrating that a small difference in conditions may be sufficient to decide between a mere holding on to life and a fair commercial success. The climatic conditions indicated in Table I for Phoenix will be a close approximation to those prevailing at this place. Plate I, figure 2, shows a characteristic tree of the south row in fruit.

THE POPE OLIVE PLANTATION, NEAR PALM SPRINGS, CAL.

DESCRIPTION.

In traveling over the Southern Pacific Railway from Los Angeles to the east, one leaves the orange groves of Colton and Redlands to ascend into a cooler region, an altitude of nearly 3,000 feet being reached in the San Gorgonio Pass. Here, around Beaumont and Banning, are flourishing orchards of prunes, peaches, and apricots, watered from the perpetual snows of the San Bernardino Range, and extensive barley fields moistened by the winter rains. A descent of 2,000 feet in 30 miles to Palm Springs station then brings one seemingly into another country. A sparse growth of desert shrubs and herbs in torrent-washed gravel and among bowlders replaces the orchards and harvest fields, and instead of the refreshing breezes from the snow-capped peaks there is much of the time a sand-laden gale blowing so steadily down the valley that all the desert shrubs lie prostrate and the drift of sand to the leeward of each makes it seem to be marking a nameless grave. Just ahead lies a low range of hills, their original rock formation barely suggested beneath the mantle of sand that centuries of winds have heaped upon them. No landscape could be in more striking contrast with that left behind at Colton and Beaumont.

Taking the trail to the southward from Palm Springs station for a few miles carries one out of the sweep of the winds to a sheltered section containing the picturesque little village of Palm Springs at the site of the old Agua Caliente. (See map, fig. 1.) The Mission Indian village lies on the east side of "Indian avenue" and a little group of homes of the white settlers on the west, all nestling under the shelter of the towering San Jacinto Mountain, whose two peaks, San Jacinto and Cornell, are among the highest in southern California. From a jagged rent in the eastern base of the mountain issues an ice-cold stream of water, a brawling torrent when the mountain showers are heavy or the snows are melting rapidly, but sinking to a tiny rivulet at the end of the long desert summer, barely sustaining life in the little oasis dependent upon it. In fact, during a series of extremely dry years it has happened that the flow of 9 or 10 miner's inches, or about 120 gallons, per minute from the hot spring pool has been all there was to sustain plant or animal life for months at a time.

A little way out on the desert one notices rows of pepper trees (*Schinus molle*), their rich, dark green in sharp contrast with the desert herbs and shrubs, while a nearer approach shows, perhaps, a half-dismantled house and a broken fence inclosing a small field. Gaunt rows of cottonwood trees, a few still keeping up the struggle, the greater part standing stiff and white, seem ghostlike sentinels keeping watch along the line of a ditch that has long since ceased to convey the life-giving water. Acres of grapevine stumps, blocks of dead apricot trees, skeleton branches of bleaching fig trees, a few green sprouts struggling from their bases—all give eloquent testimony to the energy and capital invested in the Palmdale settlement in 1889, when the granite-lined canal brought a supply of water from the Whitewater River across 7 miles of blowing sand to irrigate this sheltered spot at the foot of the San Jacinto Range.[a]

In striking contrast to the impression of desolation offered by the majority of these abandoned fields is that of a tract lying a mile northeast of Palm Springs, Cal.,[b] where, if one ascends to a little elevation above the plain, the check rows in dark, rich green of an olive plantation of 26 acres shows in striking contrast to the brownish green of the creosote bush (*Covillea tridenta*), which forms the natural growth. Here in 1891 was set an olive grove of approximately 3,000 trees, together with some 6 or 7 acres of figs. (See Pl. III, fig. 1.)

CLIMATE OF PALM SPRINGS.

Palm Springs has the typical desert climate, modified somewhat by its proximity to the San Jacinto Range, which cuts off the fierce sweep of the winds which come down through the San Gorgonio Pass and spread out over the country above the Salton Sea. The summer's heat is intense and prolonged, maximum temperatures of 100° F. and over being reached every month from May to September, inclusive, and occasionally even in April and October. The absolute yearly maximum for the ten years from 1897 to 1906, inclusive, ranges from 113° to 122° F., only 1904 failing to reach 116° F. The lowest recorded winter temperature is 28°, but more often 32° F. is the record, and sometimes winters pass with scarcely a trace of frost. Although within 12 miles of the snow-capped San Jacinto peaks, the mean annual precipitation is a scant 3½ inches, with a total of only 0.70 inch for 1903 and a maximum of 9.36 inches for 1905. (See Table III.)

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[a] Since the studies herein described were made, much of the canal stock and a considerable acreage of land have been acquired by persons who have repaired the canal and begun again the appropriation of water from the Whitewater River.

[b] A portion of section 11, in township 4 south, range 4 east.

Scant as this rainfall is it nearly all occurs in the six months from October to March, inclusive. During the six summer months when a temperature of 100° F. is reached almost daily there is scarcely a trace of rain. (See fig. 4.) That any vegetation should be able to pass through this terrible period of heat and drought seems beyond belief to one accustomed to the behavior of plant growths of the regions having abundant rainfall; yet many species of shrubs and three species of trees are native in these hot sands.

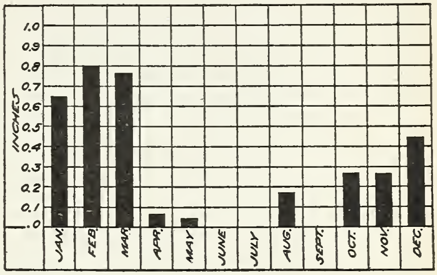

FIG. 4.—Diagram showing the mean monthly rainfall at Palm Springs station, Cal., as presented in Table III.

That the olive, whose beautiful groves are typical of the most favored portions of France and Italy, should be able to survive and even successfully compete with these desert shrubs in their own habitat, when planted among them and then abandoned, gives us a new insight into the real character of this tree that makes it worthy of careful study.

TABLE III.—*Maximum and minimum temperatures and precipitation at Palm Springs station, four miles north of the Pope olive plantation, California, elevation 584 feet, for the years 1897 to 1907, inclusive.*

MAXIMUM TEMPERATURE (DEGREES FAHRENHEIT).

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1897	68	74	83	103	108	111	120	118	104	97	89	78	120
1898	73	88	95	108	102	110	116	115	112	102	92	78	116
1899	82	84	84	102	92	116	116	114	113	96	90	86	116
1900	81	86	97	94	106	111	118	110	107	104	90	78	118
1901	78	98	96	95	98	118	111	114	106	98	90	82	118
1902	98	105	105	98	101	121	116	106	112	95	85	75	121
1903	70	72	85	97	111	112	117	116	112	98	88	81	117
1904	78	86	92	106	103	112	113	111	107	102	96	81	113
1905	72	70	81	78	110	110	122	115	110	98	82	74	122
1906	70	......	88	101	102	112	116	116	106	104	94	75	116
1907	74	84	91	100	95	115	118	......	102	100	88	78	....

MINIMUM TEMPERATURE (DEGREES FAHRENHEIT).

1897	38	32	37	40	39	65	77	81	68	55	42	30	30
1898	36	48	42	54	58	70	78	78	64	62	42	32	32
1899	30	28	46	56	60	66	85	70	70	50	50	32	28
1900	34	38	50	42	52	66	69	70	64	54	48	44	34
1901	30	44	50	58	64	61	75	80	65	65	47	30	30
1902	32	30	42	50	62	59	66	68	60	60	35	40	30
1903	40	32	46	50	54	60	65	68	58	58	50	34	32
1904	32	39	49	53	53	69	75	79	61	62	56	48	32
1905	45	28	50	46	50	60	75	80	70	60	40	30	28
1906	33	......	42	50	58	62	84	70	62	47	32	40	....
1907	30	46	42	55	52	70	72	......	60	60	46	35	30

TABLE III.—*Maximum and minimum temperatures and precipitation at Palm Springs station*—Continued.

PRECIPITATION (INCHES).

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1897	0	0	0	0	0	0	0	0	0	0	0	1.09	1.09
1898	......	0	0.60	0	T.	0	0	0	0	0	0	.70	....
1899	1.21	0.12	0	0	0	0	0	0.62	T.	0	0.50	2.86	5.31
1900	.80	0	0	0	0	0	T.	0	0	1.29	T.	0	2 09
1901	T.	3.50	0	0	0	0	0	0	0	0	0	0	3.50
1902	.50	0	.50	0.50	0	0	0	0	0	0	.70	.70	2.90
1903	0	0	.70	0	0	0	0	0	0	0	0	0	.70
1904	T.	T.	......	0	0	0	0	1.00	0	.10	T.	0	....
1905	2.16	3.95	1.66	T.	0.48	0	0	0	0	0	1.11	0	9.36
1906	.46	......	3.05	.20	0	0	0	.10	0.05	0	.70	.56	....
1907	1.27	.47	1.27	.15	0	0	0	......	0	1.64	0	T.	....

T.=trace.

SOIL AT PALM SPRINGS.

The soil of the olive orchard is typical of this district. The rock formation is coarse sandstone and granite. The southern face of the mountains is broken by canyons of various widths and depths, originating as rents and fissures in the uplifted rock, but enlarged by the erosion of the mountain torrents, which were apparently during glacial times of vastly greater volume than at present. The result has been an enormous talus of water-worn bowlders from each of the main canyons extending out into the basin to an unknown distance and depth and spreading laterally along the mountain base. Over this is a varying depth of coarse sandy and gravelly soil, in places mixed with a considerable quantity of finer material from the sorting action of wind and water. Several square miles in the Palm Springs and Palmdale region have thus a fair quality of sandy soil, which is lacking in sufficient clay or fine binding material and because of the scanty rainfall and sparse vegetation is low in organic matter. Judging from the quantity of feldspar in the original granitic rock, there is doubtless a good deal of available potash in this soil.

On the particular 40 acres in the olive orchard there is rather less of the finer material in the soil than in that of the Indian reservation lands adjoining on the south. Layers of coarse gravel and cobblestones are often encountered at depths of 3 to 4 feet. The longest winter rains sink so quickly into the soil that there is no trace of stickiness or mud on the following day.

TABLE IV.—*Mechanical analyses of soils from olive orchards at Casa Grande, Ariz., and Palm Springs, Cal., made by the Bureau of Soils, U. S. Department of Agriculture, from samples collected by Mr. S. C. Mason.*

Locality.	Depth taken.	Fine gravel, 2 to 1 mm.	Coarse sand, 1 to 0.5 mm.	Medium sand, 0.5 to 0.25 mm.	Fine sand, 0.25 to 0.1 mm.	Very fine sand, 0.1 to 0.05 mm.	Silt, 0.05 to 0.005 mm.	Clay, 0.005 to 0 mm.
	Inches.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Casa Grande, Ariz	0 to 6	4.0	15.1	10.4	25.0	11.1	27.1	8.0
Do	6 to 12	3.7	13.5	9.1	26.0	10.0	32.3	5.0
Do	12 to 18	4.4	14.0	9.4	25.0	9.1	32.1	6.6
Palm Springs, Cal	0 to 6	4.0	15.2	42.0	17.7	13.2	7.2	.8
Do	6 to 12	4.0	15.0	15.4	43.4	13.1	8.0	.9
Do	12 to 18	3.4	14.1	14.0	40.2	14.9	11.3	1.6

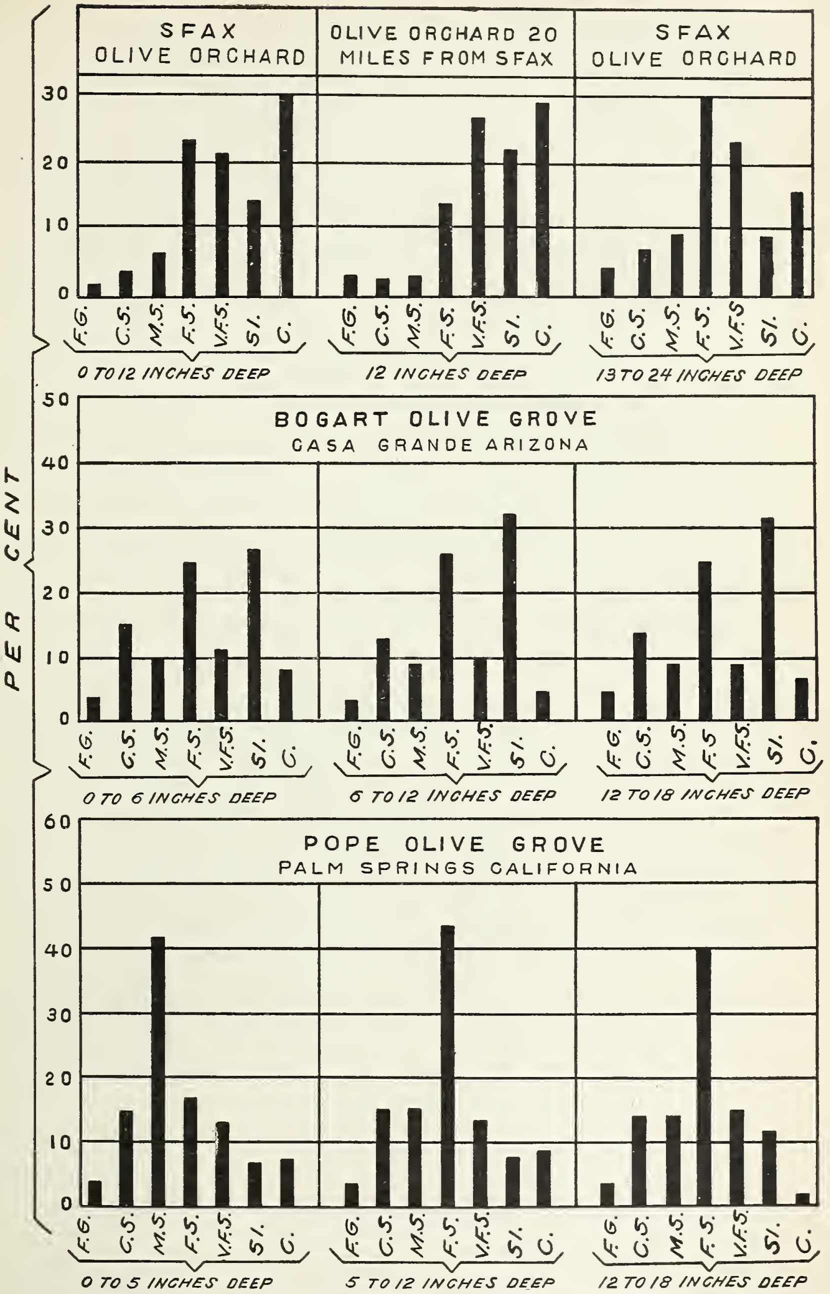

FIG. 5.—Diagram showing the relative percentages of fine gravel, coarse sand, medium sand, fine sand, very fine sand, silt, and clay in dry-land olive plantations in northern Africa (Sfax) and in Arizona and southern California.

TABLE V.—*Analyses for potash, phosphoric acid, calcium, and organic matter in soils from olive orchards at Casa Grande, Ariz., and Palm Springs, Cal., made by the Bureau of Soils, U. S. Department of Agriculture, from samples collected by Mr. S. C. Mason.*

Locality.	Depth taken.	CaO.	K_2O.	P_2O_5.	Organic matter.
	Inches.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Casa Grande, Ariz	0 to 6	1.18	0.98	0.03	0.15
Do	6 to 12	.53	1.00	.22	.46
Do	12 to 18	1.85	1.00	.32	.66
Palm Springs, Cal	0 to 6	1.58	.81	.52	.19
Do	6 to 12	1.58	1.02	.38	.12
Do	12 to 18	1.75	.80	.41	.17

Figure 5 shows in a graphic manner the results of a mechanical analysis of this soil by the Bureau of Soils, as presented in Table IV. This is placed for comparison below a diagram showing the results of a similar analysis of the soil from the Casa Grande olive grove and one from the olive orchards of Sfax.[a] The small quantity of clay and silt and the large proportion of medium and fine sand distinguish

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[a] See "Dry-land Olive Culture in Northern Africa," by Thomas H. Kearney, Bulletin 125, Bureau of Plant Industry, U. S. Dept. of Agriculture, 1908, pp. 18–19, as follows:

Mechanical analyses of soil samples from the olive orchards of Sfax.

Locality.	Depth taken.	Fine gravel, 2 to 1 mm.	Coarse sand, 1 to 0.5 mm.	Medium sand, 0.5 to 0.25 mm.	Fine sand, 0.25 to 0.1 mm.	Very fine sand, 0.1 to 0.05 mm.	Silt, 0.05 to 0.005 mm.	Clay, 0.005 to 0 mm.
	Inches.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Olive orchard, Sfax	0 to 12	0.2	4.3	7.1	24.1	20.9	14.1	30.0
Do	13 to 24	.4	7.7	9.7	33.9	24.0	9.1	16.0
Do	25 to 36	.5	7.9	10.3	34.3	24.6	7.1	15.7
Do	0 to 12	.2	4.6	6.8	26.4	22.5	13.4	26.2
Olive orchard, 20 miles north of Sfax	(*a*)	.3	2.7	3.3	14.9	27.0	22.9	29.3

[a] Adhering to olive truncheons, probably about 12 inches.

Chemical analyses of a large number of samples of the Sfax olive soils by the chemist of the Tunisian government show them to be very rich in lime (calcium carbonate), of which there is an average of from 5 to 10 per cent. The potash content is also good, the average being 0.1 to 0.2 per cent. On the other hand, they are rather poor in nitrogen (0.03 to 0.05 per cent) and in phosphoric acid (0.04 to 0.05 per cent). According to Trabut, a high lime content is a very favorable factor in growing olives for oil production, as olives produced in limestone regions are richer in oil and the oil is of better quality then where the soils are deficient in this component. It should be noted that while the nitrogen and phosphoric acid content of the Sfax soils would be considered low for most crops, the high yields and good quality of the oil produced at Sfax are sufficient evidence that the supply of these two elements of plant food must be amply sufficient for the requirements of the olive. This can perhaps be explained by the fact that the roots of this tree occupy so great an area of soil (one-seventh to one-tenth acre) that, while the percentage of these elements to weight of soil is everywhere low, the total amount available to the roots is actually rather high.

this Palm Springs soil in a very marked way from that of the Casa Grande. Both are in striking contrast with samples from the dry-land olive district of Sfax, in northern Africa, described in Mr. Kearney's bulletin previously referred to. The much higher percentage of clay in the Sfax samples gives a very distinct character to that soil, which as it exists in nature impresses one as sandy, owing doubtless to the clay and silt particles being cemented together.

In chemical composition these soils (Table V[a]) show a striking similarity in the lime content, having only one-eighth to one-fourth as much of that element as is found at Sfax.

In the amount of potash the Casa Grande and Palm Springs samples are also very much alike, being five to ten times richer than the Sfax samples. In the amount of phosphoric acid it is interesting to note that the Palm Springs soil, though seemingly a desert sand, contains more than twice as much of this important element as is found in the Casa Grande samples. In the potash and phosphoric acid contents either of these samples compares favorably with average agricultural soils; for instance, with the soils of the famous Michigan peach belt,[b] while in phosphoric acid the Palm Springs samples, averaging 0.436 per cent for the entire 18 inches in depth, are ahead of all but the very richest farm lands of the eastern United States. This richness of desert soils in phosphoric acid and potash is especially advantageous to olive culture, as investigations by the California Agricultural Experiment Station have shown that the olive makes much higher demands upon the soil for these elements than do grapes, plums, apricots, or oranges.[c]

HISTORY OF THE GROVE.

As nearly as can be gathered the greater part of the Pope olive orchard was set in 1890 and 1891. There was at that time an adequate supply of water available from the Whitewater ditch, which was conveyed to each block of land by box conduits. Along these conduits and across the north side of the blocks rows of cottonwood trees were set 20 feet apart. Their influence on the olive plantation will be referred to later.

The olive trees were planted 21 feet apart on the hexagonal system, giving 116 trees to the acre. For the first seven or eight years there was a fair supply of water. No Bermuda grass or other serious weed gained a foothold and the work of irrigating the trees was the chief labor. It can not be learned that during that time any fruit was produced. A resident of Palm Springs who came there in 1896 recalls that they were "expecting the trees to come into bearing the next year." About this time difficulties with the water supply began, and as nearly as can be ascertained no irrigation at all has been given the orchard since 1900.

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[a] From analyses by Mr. Joseph G. Smith, of the Bureau of Soils, U. S. Dept. of Agriculture.

[b] See Roberts, I. P., "The Fertility of the Land."

[c] Report of the Director of the California Agricultural Experiment Station, 1894–95, p. 124.

PRESENT CONDITION OF THE GROVE.

The first fact with which one is impressed on seeing this plantation is the small size of the trees considering their age. Some trees are scarcely 4 feet high, and very few more than 7 or 8 feet. Taking two average rows, the range in height was found to be from 41 inches to 98 inches, the average for 50 trees being 63.5 inches. The highest tree in the 20-acre block was found to be 9 feet, while only 10 trees could be found measuring 8 feet and upward. (See Pl. III, fig. 2.)

It is to be noticed that on these trees the branches are retained clear to the ground and that the breadth of the top exceeds the height in almost every case, so that in the 50 trees examined only one was found in which the height was greater than the breadth of top. The average breadth for the two rows is 79.5 inches as against 63.5 inches of height. These tops, too, are much branched and very compact. In nearly every case the trunk is concealed. A leafy canopy protects the trunk and main branches from the dry air and fierce heat of the desert sun.

In doing battle for their lives in the desert they have shown their ability to adapt themselves to desert methods of defense. The mesquite and paloverde,[a] the largest native trees, may attain a spread of top of 40 or 60 feet with a height of only 20 or 30 feet. The desert willow (Chilopsis) and the *Dalea spinosa,* two species somewhat less resistant to drought and heat, attain a treelike size by throwing out a defense of sprouts and low branches, or, failing in this, they are apt to show scars of severe sun scalding.

The so-called "wild apricot" (*Prunus fremontii*), venturing out a little way along the bowlder talus from the canyon's mouth, has a top so densely branched, angled, and interlocked as to well merit the name Emplectocladus, signifying interlocked branches, which now applies to the whole subgenus to which it belongs.

Similar proportions of height to spread of top will be found in nearly all of the characteristic desert shrubs, the effort seeming to be to throw as much shade and insulation as possible around the trunk and main branches.

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[a] *Cercidium torreyanum* (Wats.) Sargent.

This purpose is accomplished most effectively and in the most characteristic way of all by that typical desert tree, the majestic palm (*Washingtonia filifera*), whose dying lower leaves suspended by their long petioles form a dense thatch, completely insulating the tall, columnar, branchless trunk against both the direct and reflected heat of the sun and the drying winds. Where some vandal hand does not apply a torch, this splendid protection is retained for many years, perhaps for life.

It is probable that in the case of the olive, as well as of many native desert plants, this low, spreading canopy of top serves another purpose. Of the total precipitation for the year in these regions a considerable proportion is in the form of small showers, so that the monthly record will often be indicated by such fractions of an inch as 0.12, 0.09, 0.32, 0.06, trace, etc., these usually representing a single precipitation. Such an amount falling upon the parched soil in the open is so soon evaporated as to afford little aid to the thirsty plant. Arrested by the leaves or fine branches and carried to the ground at the base of the stem, it is so shaded and conserved as to be allowed to sink into the surface soil, where a system of short, finely branched superficial roots is ready to appropriate it. In Plate IV, figure 2, such rootlets of the olive tree are shown in natural size.

Inspection of the whole 26 acres of the plantation shows that several varieties were set, just what they were being difficult to decide with accuracy, no plat or planting list so far having been discovered. The block in which the most trees are alive and in the best condition, though not making the largest growth, has the dense, compact habit and broad top most completely developed, and here any exposure of trunk or main branches to the sun is hard to find. These trees are noticeable for the complete absence of any sun scald on the bark.

The northern seventeen rows of this block are ranker in growth and more coarsely branched, and while the leaves are larger the whole canopy is much thinner. Of this variety, probably Manzanillo, a quarter of the trees are dead and others have suffered severe sun scald. In other cases a portion of the top has died back, to be followed by a vigorous sprouting from below. Of a block of four rows adjacent to this, not 10 per cent of the trees are alive, but these appear to be of a variety little adapted to these conditions.

The cottonwoods already referred to, bounding the 20-acre block on the west and north sides, are all dead, but so also are the olive trees next to them. Of the Manzanillo olives, the two rows on the north and next to the cottonwoods are two-thirds dead, while the third row is in bad condition. Of the trees on the west ends of the rows next to the cottonwoods in the larger block not so large a proportion is dead, but those alive are small and in bad condition. Figure 6 shows very distinctly the effect of the cottonwood growth on the olives. The struggle has been so intense for a bare survival on the part of the whole plantation that the competition with a powerful feeder like the cottonwood has proved fatal, though the cottonwoods probably survived the olives but a few years.

Crossing the conduit to the next 20-acre block, only half of which was set, are two small blocks of olives, 6 acres in all, with 4 acres of figs between them. Here the contrast between the green of the olives on either side and the figs, which are dead save a few struggling sprouts, illustrates in a most marked way the comparative drought resistance of the two. Indeed, of exotic trees on this ranch only the pepper trees bordering one field show an ability to endure these extreme conditions equal to that of the olive.[a]

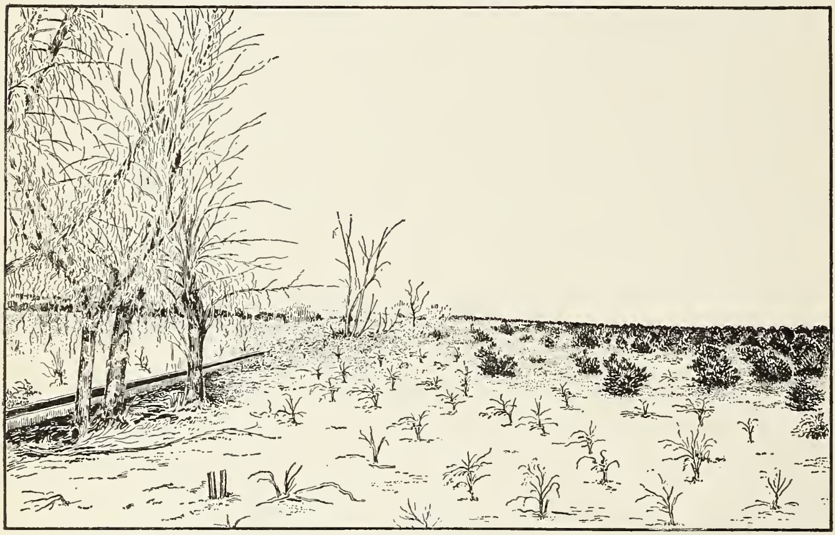

Fig. 6.—Olive trees which have died through competition with a row of cottonwood trees on the Pope olive plantation, near Palm Springs, Cal. (From a photograph.)

While trees of this slow growth and evergreen nature are consequently slow in forming what the foresters call dominant and suppressed classes, a close inspection of this grove shows such a work to be in progress, not as is generally the case in a forest by the process of dominant trees overtopping and shading the weaker ones, but by means of dominating root systems by which once a tree has gained the ascendancy in water appropriation it will sooner or later have three or four adjacent trees in the suppressed class. This suppression of the weak trees by the stronger rooted dominant ones begins as soon as the roots meet in the intermediate territory, which has happened in many instances in this grove and seems to account for the death of many of these trees and the weak condition of others. This affords conclusive proof that olive trees can not be grown successfully 21 feet apart under light rainfall without ample irrigation, and, what is more significant, that when given wide planting they are capable of extending their root systems and collecting their water supply from a very wide area.

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[a] A visit was made to this plantation on April 13, 1908, at which time about 20 per cent of the trees of the more resistant variety of olives was in blossom, but at a later visit, June 11, not a single fruit could be found to have set. On the same date two olive trees in Dr. Wellwood Murray's irrigated garden in Palm Springs village were carrying fair crops of fruit.

OLIVE ROOT SYSTEMS ADAPTED TO UTILIZE LIMITED RAINFALL.

The remarkable endurance of drought displayed by the olive trees of which an account is given in this paper, but especially by those at Palm Springs, Cal., must be explained (1) by unusual ability to collect moisture from a soil supply normally deficient and (2) by an ability to conserve that moisture and perform their physiological work on a supply that would prove totally insufficient for ordinary trees. For the first we must look to the roots, and as these were uncovered and plotted it became evident that the deeply penetrating system possessed by the mesquite for bringing up water from a subterranean source was not possessed by the olive, nor would it have availed much, as on near-by land a well had been sunk to a depth of 80 feet, disclosing only dry cobblestone and gravel. No penetrating taproots were found, but usually each tree had a deeply-seated burl or swelling two or three times the diameter of the trunk above ground, from which radiated evenly in all directions a strong set of roots running off nearly horizontally. Plate IV, figure 1, shows the trunk, burl, and main roots of a tree which was selected for study from the most resistant variety of the Pope plantation.

This tree was barely 6 feet in height, with a top spread of 7 feet and a trunk diameter of 3¾ inches; yet we find a root system radiating to 10 and 11 feet in nearly all directions and having a total length of roots of one-eighth of an inch in diameter and upward of about 185 feet. The length of roots was at least double that of the twigs and branches of similar diameter, while the area occupied by the roots was nine times that of the spread of the branches.

The strongly gnarled burl was a foot in depth, and from this the roots issue at depths of 2 to 10 inches. With but a few exceptions they all break up into fine rootlets at depths of 5 to 8 inches, the greatest number being at 6 inches. In two cases small laterals penetrate to 18 inches in depth, and there was a curious case of branches from two separate roots going down at the same point—possibly an old burrow of some rodent affording a more mellow soil—to 36 and 42 inches, respectively, beyond which point they were not excavated and were still one-eighth of an inch in diameter.

The block of the Manzanillo variety at the north end of the 20 acres showed a different behavior from that of the main body of the grove. The wood growth averaged much ranker, but the branches were coarser and the tops more open to the sun. Far less adaptability to conditions is evident. Dead trees, trees with dead tops but with live sprouts from below, dead branches, and sun-scalded spots on exposed places are to be seen on every side. In this block the tree selected for study was 8 feet high, with 8 feet spread of top and a trunk 5 inches in diameter. A still stronger root system was found here, there being ten roots of from three-fourths of an inch to 1½ inches in diameter springing from the burl at the following depths below the surface: Two at 2 inches, one at 3 inches, one at 12 inches, three at 14 inches, two at 16 inches, and one at 18 inches. It being evidently impossible to keep track of all of these at one excavation the surface roots were excavated by themselves. These comprised three strong roots, issuing at 2 and 3 inches below the surface, and a circle of short fine roots, which the writer called the shade roots from the fact that they occupy the space immediately beneath the spread to the top.

Figure 7 shows these superficial roots represented in solid lines, while the deeper roots are shown by dotted lines, but it should be noticed that a number of the shallow roots figured came up to join this class from roots of deep origin. These shallow roots taken together may be regarded as a very important part of the equipment of the tree. Their rootlets reach to quite near the surface, so that they are prepared to gather moisture from a small rainfall. The shade roots appear to collect also the water which is arrested by the top and runs off to the ground from the trunk. It must be remembered that the medium in which these trees grow is so nearly pure sand as scarcely to be called a soil. There is a good deal of fine material in it, but it does not bake or pack, and cracks never occur. It is very doubtful whether any method of soil culture, dust mulch, or subsurface packing would be of value here. All that such treatment is expected to accomplish is already insured by the nature of this soil, and, furthermore, any cultivation would only destroy these delicate rootlets so nicely adapted to taking advantage of the lightest rainfall. Referring to the deeper roots in figure 8, we notice first the large area occupied by them as compared with the spread of the top. The roots of this tree over one-eighth of an inch in diameter have a total length, including the upper layer, of approximately 376 feet. The area of the root spread, as compared with the spread of the top, would be a little more than 7 to 1.

The depth of the course followed by these large roots of 12 to 18 inches is a very marked feature. Most interesting is the deep penetration, almost vertically, of branches from many of these roots to depths of 2, 3, 4, and even 5 feet, where they were left, owing to the difficult nature of the digging. In most cases gravel and cobblestones of considerable size were encountered at these depths, and as

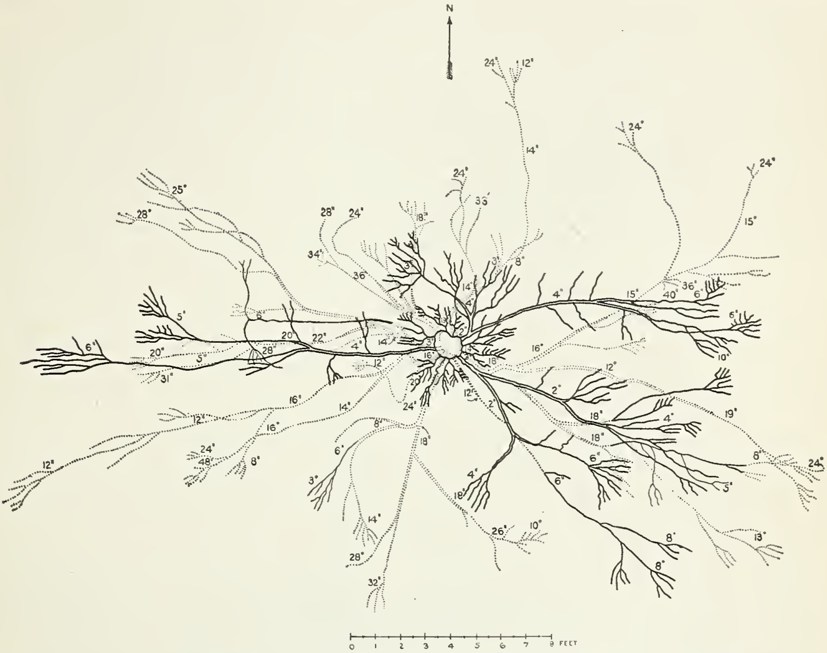

FIG. 7.—Diagram showing the distribution of superficial roots (solid lines) and deep roots (dotted lines) of a Manzanillo olive tree on the Pope olive plantation, near Palm Springs, Cal.

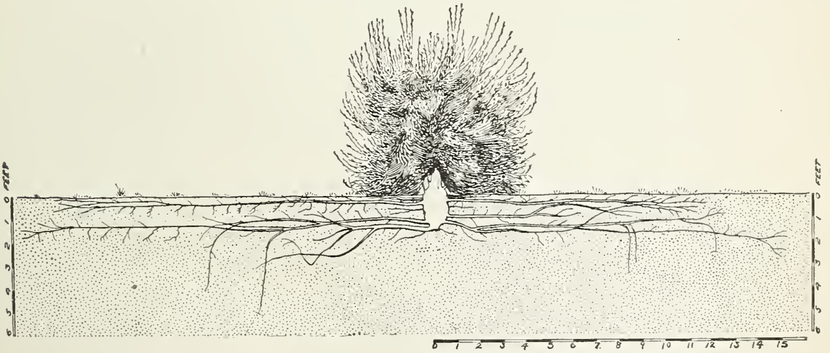

FIG. 8.—Diagram showing the root system of a typical dry-land olive tree on the Pope olive plantation, near Palm Springs, Cal., showing the position and distribution of the roots in the soil.

these were all old, hard roots it seems probable that they had gone down to these depths during the years when the orchard was still irrigated. The rootlets branching from these and all the deeper lying roots were much fewer than those nearer the surface.

A point previously referred to of special interest in this study is that of a number of deep-lying roots at points several feet from the tree sending off branches which rise suddenly to the level of 4 to 8 inches, along which levels they make a growth of several feet, sending off numerous branchlets and small feeding rootlets. These ascending laterals were found to show but three or four rings of annual growth while the main root (though it was impossible to count the rings accurately) was several years older. Evidently the upper growth had been made since irrigation ceased in an effort to reach the more favorable conditions for moisture and air at the upper level. In both trees studied, as well as in many others where small excavations were made, fine-feeding rootlets were found in considerable numbers at 2 to 24 inches in depth, but the zone of their greatest abundance was at 4 to 10 inches. Plate IV, figure 2, shows a section of a long root from a depth of 6 inches, with lateral branches and feeding rootlets, from a photograph of exactly natural size.

MOISTURE ECONOMY AIDED BY THE STRUCTURE OF THE OLIVE LEAF AND STEM.

In addition to the elaborate arrangement of olive roots for collecting the last particle of moisture possible from a sandy desert soil, there must still exist a remarkable economy in tissues and functions to enable a tree to survive, not to say to make growth, under such conditions.

It is to the leaves that we must look chiefly for this work. Their narrow form, reflexed margins, thickness, and tough leathery texture, as well as the densely hairy, almost felted under surface, all indicate that they are prepared to resist to the extreme the drying influence of the desert air. The minute anatomy of the leaf and stem of the olive has received considerable attention from botanists, but apparently no attempt has hitherto been made to ascertain to what extent different environments affect modifications of structure. That some light might be had on this most interesting point, material was procured by the writer of this bulletin from olive groves of California and Arizona, the samples being obtained from such widely diverse environments as the moist, fog-laden air and ample irrigation of Niles, near the San Francisco Bay, and the extreme of desert dryness and heat of Palm Springs, Cal. These were placed in the hands of Dr. Theodore Holm, whose study of them, illustrated in Plate V, figures 1 and 2, and five text cuts, is given in the Appendix to this bulletin.

SUCCESSFUL DRY-LAND OLIVE CULTURE IN CALIFORNIA.

In contrast with the mere endurance test of which the preceding examples are very instructive illustrations, there is in the so-called "inside" region of southern California, between the ocean and the mountains, an olive industry based on the local rainfall on lands above canal lines or lacking a sufficient water supply. Excellent examples of this type of olive culture may be found in the neighborhood of Beaumont, Riverside County; La Mirada, Orange County; Chatsworth and San Fernando, Los Angeles County; in Santa Barbara County; and also in the more northerly part of the State near Oroville.

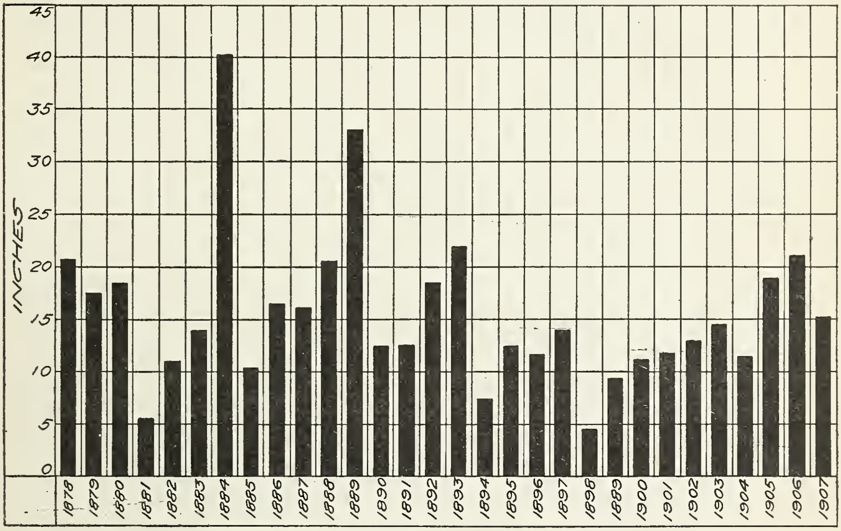

FIG. 9.—Diagram showing the annual rainfall at Los Angeles, Cal., as presented in Table VI.

While varying considerably in their climatic conditions they all agree in these general features: A minimum temperature never below 20° and seldom lower than 28° or 30° F.; a maximum summer temperature of 105° in cooler seasons to 114° F. in extremely hot years, but with a monthly mean temperature not below 48° in winter and seldom exceeding 80° F. in summer. From a study of Table VI, represented graphically in figure 9, we may see that the annual rainfall at Los Angeles has exceeded 12 inches during more than half of the years recorded, occasionally rising to 22 or 23 inches, or even higher, and only in rare years of drought falling as low as 7½ inches, with the minimum of 4.83 inches during the thirty years recorded.

TABLE VI.—*Annual rainfall at Los Angeles, Cal., 1878 to 1907, inclusive.*[a]

Year.	Inches.	Year.	Inches.
1878	20.86	1893	21.96
1879	17.41	1894	7.51
1880	18.65	1895	12.55
1881	5.53	1896	11.80
1882	10.74	1897	14.28
1883	14.14	1898	4.83
1884	40.29	1899	8.69
1885	10.53	1900	11.30
1886	16.72	1901	11.96
1887	16.02	1902	13.12
1888	20.82	1903	14.77
1889	33.26	1904	11.88
1890	12.69	1905	19.19
1891	12.84	1906	21.31
1892	18.72	1907	15.30

[a] For the data used on the climate of California, the writer is indebted to Mr. A. B. Wallaber, of the Climate and Crop Service of the United States Weather Bureau at Los Angeles, Cal.

TABLE VII.—*Mean relative humidity at Los Angeles, Cal.*[a]

Month.	5 a. m.	5 p. m.	Month.	5 a. m.	5 p. m.
January	67	64	August	87	63
February	73	63	September	82	63
March	80	65	October	78	68
April	82	63	November	64	65
May	87	65	December	61	64
June	87	61			
July	90	62	Year	78	64

[a] For the data used on the climate of California, the writer is indebted to Mr. A. B. Wallaber, of the Climate and Crop Service of the United States Weather Bureau at Los Angeles, Cal.

The rainfall of this region is enhanced by frequent coast fogs. The mean relative humidity from month to month is an important factor in all such cultural problems, but this is obtainable only for Los Angeles, with which point we may fairly compare Los Angeles County and Orange County. This, it will be seen from Table VII, ranges from 61 to 90 per cent for the 5 a. m. observation, and from 61 to 68 per cent for the 5 p. m. observation. This condition of atmospheric moisture would give orchards in these localities a great advantage, for instance, over the one studied at Palm Springs in the edge of the Colorado Desert, except that the trees suffer more from the attacks of parasites in the more humid climate.

One of the most extensive examples of olive culture without irrigation in this region is to be found on a large ranch in the southern part of Los Angeles County, near La Mirada, Cal. Here are 500 acres in olives, the oldest set sixteen years ago and others as recently as seven or eight years ago. The planting distance was only 20 feet, giving 108 trees to the acre. The olives occupy rolling hillside land for the most part, difficult of irrigation even if a water supply were at hand. The soil is as a rule a rather strong adobe, with some admixture of sand in parts of it. The nature of the hills nearest would indicate an abundance of lime in this soil, which is so important for olive production. Some degree of cultivation is given between the rows, but with the older trees the spread of the branches prevents reaching all of the surface.

The original plan was to remove half of the trees as they began to crowd by cutting out every other row on the diagonal. The effect of this is to leave one-half, or 54 trees to the acre, in rows 20 feet apart, and trees 40 feet apart in the row alternating. This has been done with some blocks of the older trees and is a very evident gain. Where the original stand of the older trees still remains there is evidence of crowding and lack of thrift in many cases, and the writer is convinced that a stand of only 27 trees to the acre, or 40 by 40 feet, would be still better as the trees advance in age. The great vigor and productiveness of the trees along the draws and low places where any surplus of rain would flow give evidence that water famine had been felt by the small trees.

A notable feature of this orchard was the prevalence of the common black scale, a parasite found on olive trees all along the range of the ocean fogs unless vigorously combated, and not found to a harmful extent in the interior valleys of California or Arizona. How seriously this scale interferes with the functions of the tree is a matter upon which olive growers differ widely, but there is no difference of opinion as to the scale preventing the production of an olive of good pickling qualities.

Of the varieties planted, the Mission is the most prominent and satisfactory, though considerable blocks of the Nevadillo, the Pendulina, and the Columbella are also grown.

Plate VI, figure 1, shows a general view across a small valley in this orchard, and figure 2 a view among the rows of older trees thinned by removing alternate diagonal rows.

In comparison with this orchard stands the case of a ranch 2 or 3 miles away, the soil and location being practically the same. Here 400 or more acres of olives, probably differing little at the start, have for several years been in absolute neglect. Many of the trees were never properly headed up, being mere stools of several shoots from the ground. No evidence of cultivation could be seen, but grass, weeds, and small shrubs robbed the trees of the needed moisture. This, with the close planting, had reduced the problem to one of existence instead of profitable production. There was some fruit, and occasional trees enjoying some little advantage in space and moisture were bearing fair crops. These only helped to prove the fallacy of the idea that the olive is a tree that may be planted upon dry and barren soil, given absolute neglect, and yet produce profitable crops of fruit. Here in these contrasted orchards, with soil, rainfall, and temperature similar, the difference between pruning and culture on one hand and neglect on the other made the difference between a profitable industry with a fine product and a poor and scant crop not worth going over the ground to gather.

AREA OF POSSIBLE DRY-LAND OLIVE CULTURE IN THE UNITED STATES.

AREA LIMITED BY THE MINIMUM TEMPERATURE.

Of the factors defining the area of olive culture in the United States, that of minimum temperature is the most important.

It has been claimed by some authors [a] and by many olive growers that an actual minimum temperature of 14° or 15° F. will prove fatal to the olive tree. It is undoubtedly true, however, that the olive will endure considerably more cold than this if it is in a thoroughly dormant condition. This is especially true where the atmosphere is dry and where the low temperature persists for only a short time, possibly a few minutes at near daylight, as is so often the case in the southwestern sections.

As an illustration of these ideas, in 1899,[b] from February 11 to 13, a cold wave of unusual intensity swept over a great portion of the Southwest, temperatures of −6° to −23° F. being recorded in northern Texas, and as low as 8° F. in the southwest border.

At San Antonio two stations gave minimum records of 4° F. At Fort McIntosh, on the Rio Grande near Laredo, a minimum temperature of 5° F., probably for only a brief period, was recorded on the morning of February 12, and at Fort Ringgold, 90 miles down the river, a temperature of 7° F. was recorded on the morning of February 13.

An olive grove of an acre or more about 2 miles from Fort McIntosh suffered some killing back, though the trees were not seriously injured and may be seen to-day looking as vigorous as any in the olive-growing districts of California or Arizona.

At the dry-land experiment station of the Bureau of Plant Industry, near San Antonio, Tex., young olive trees of the Chemlali variety endured a minimum temperature during the winter of 1907–8 of 18° F., with but a slight killing back at the tips. Yet in 1909 these olive trees and trees of several varieties planted in 1908 were with one exception killed to the ground under conditions where the minimum temperature reached was only 18° F. After mild weather during the latter part of December and the early part of January, with maximum temperatures of 76° and 77° on January 9 and 10 and 63° F. on the following day, a "norther" brought the temperature to 20° at 3 p. m. on January 11, with a minimum of 18° F. at night. On January 12 the minimum was 18° with a maximum of only 22°, and there was a minimum of 22° on the morning of January 13, the temperature thus being maintained about forty hours at from 10° to 14° below freezing. These trees were in a plat which in accordance with the general cultural policy of the farm had been kept under fine surface tillage, enabling the soil to store abundant moisture from the season's rains. This arrangement prevented the olive trees from entering the dormant condition necessary to their resisting the low temperatures, and the freezing sap burst the bark of most of them and killed all to the crown, from which they sprouted again freely.

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[a] A temperature of 5° C. below zero (or 23° F.), followed by a sudden thaw operated by the sun's rays, is sufficient to kill it totally at the base. With a lower temperature not followed by sunny days the plant does not suffer as much, as it can stand a cold of 10° C. below zero (or 14° F.).—*Olive Culture, Italy, Annual Report of the State Board of Horticulture, California, 1890, p. 449.*

"A low temperature, say 14° F., is fatal to the tree."—*B. M. Lelong, Investigation Made by the State Board of Horticulture of California Olive Industry, Sacramento, 1900, p. 8.*

"The olive can grow in all regions where the minimum temperature does not fall below −7° or −8° C. and does not last more than eight days."—*Translation from Hidalgo Tablada.*

[b] Annual Summary, 1899, Texas Section, Climate, and Crop Service, Weather Bureau, U. S. Dept. of Agriculture.

At Boerne, 30 miles northwest of San Antonio and 700 feet higher in altitude, the temperatures registered were 1° lower each day of this cold spell than those at the San Antonio farm, yet the olive trees there sustained much less injury.

A region may have monthly mean temperatures and an annual mean sufficient to place it high in the scale when compared with well-known olive regions, yet where high winter means include sudden drops and low minima the trees will suffer all the more severely. As an example, the monthly mean temperatures at San Antonio are higher throughout the year than those of Fresno, Cal., or of Catania, in Italy, and excepting only the autumn months, higher than those of Sfax, in Tunis, three representative olive-producing regions. Yet the liability to the sudden advance of cold waves may upon experimentation be found to exclude this portion of Texas entirely from the olive-growing belt.

It seems probable also that there is a considerable difference in olive varieties in resistance to cold, and an inviting field for experimentation is here offered.

The high altitudes of the greater portion of New Mexico will doubtless exclude the olive on account of too severe cold. However, it seems probable that favored mesa sites may be found in the southwestern portion of the Territory, particularly in Grant and Dona Ana counties, where the olive may be grown.

French authorities [a] give the maximum range in altitude for the olive as from 500 meters (1,600 feet) in France and northern Italy to

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[a] Investigation Made by the State Board of Horticulture of the California Olive Industry, Report to Governor Gage, 1900, p. 8.

700 meters (2,300 feet) in Sicily, it being even affirmed that it ascends as high as 800 meters (2,600 feet) on that island.

Simmonds, in his "Tropical Agriculture," states that the olive grows at Quito, under the equator, at a height of 8,000 feet above sea level.[a]

According to the reports of the California State Board of Horticulture[b] the olive does well at an altitude of 3,000 feet at 37 degrees latitude in the Sierra Nevadas. In the southern part of Arizona it is probable that it may thrive at still higher altitudes, possibly at 5,000 feet. Nor could a safety line of altitude alone be defined, for some higher spots favorably situated will be found to be more reliable than lower locations adjacent.

In California the olive grows well around San Diego, and from there along the coast northward to the upper end of the State and up into small valleys of the Coast Range. Farther inland the success would be limited by altitude, but it can be depended upon throughout upland portions of the greater area of the interior valleys and to altitudes of about 3,000 feet in the foothills. In Arizona areas of olive territory may be looked for as far north as the Gila River in Pinal County and farther west to the north line of Maricopa County, with probably the western limit at about the meridian of Gila Bend, on account of reduced rainfall. (See Table VIII.)

TABLE VIII.—*Localities in Arizona where dry-land olive culture may be possible, with meteorological record.*[c]

Station.	Length of record.	Altitude.	Mean annual temperature.	Minimum for 1908.	Date of killing frost, 1908.		Precipitation, 1908.
					Spring.	Fall.	
	Years.	*Feet.*	° *F.*	° *F.*			*Inches.*
Congress	12	3,668	67.2	29	Feb. 4	Nov. 9	13.15
Columbia	10	1,900	68.2	29	Feb. 16	Nov. 25	15.40
Kingman	7	3,362	61.2	22	June 4	Oct. 18	11.77
Jerome	12	4,743	60.8	22	Apr. 17	Sept. 29	18.32
Cline	9	2,300	63.9	23	Apr. 9	Oct. 24	15.94
Globe	6	3,525	62.9	24	Mar. 28	Oct. 19	16.51
San Carlos	19	2,456	....	23	Apr. 4	Oct. 21	12.78
Phoenix	14	1,108	69.5	30	Mar. 8	Dec. 21	[d]7.88
Dudleyville	18	2,360	65.0	24	Mar. 23	Oct. 22	14.00
Tucson	28	2,390	67.5	22	...do....	Oct. 19	10.69
Benson	25	3,523	66.1	21	...do....	...do....	9.03
Oracle[e]	16	4,500	62.0	10	Mar. 29	Dec. 4	25.90
Tombstone	10	4,550	62.1	25	Feb. 28	Nov. 18	14.00

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[a] "In the neighborhood of Quito, situated under the equator, at a height of 8,000 feet above the level of the sea, where the temperature varies even less than in the island climates of the temperate zone, the olive attains the magnitude of the oak, yet never produces fruit."—*P. L. Simmonds, Tropical Agriculture, p. 393.*

[b] Investigation Made by the State Board of Horticulture of the California Olive Industry, Report to Governor Gage, 1900, p. 8.

[c] Annual Summary, 1908, Arizona Section of the Climatological Service of the Weather Bureau.

[d] Mean annual, Weather Bureau, U. S. Dept. of Agriculture.

[e] Climatology of the United States, Bulletin "Q," Weather Bureau, U. S. Dept. of Agriculture.

AREA LIMITED BY HEAT REQUIREMENTS.

While the Pope olive grove has been studied as a case of survival without fruiting in spite of extreme adverse conditions, yet in the garden of Dr. Wellwood Murray at Palm Springs Hotel, with an ample shelter belt of trees around the border, two trees of the Pendulina variety have made a good growth and ripen fair crops of fruit with only scant irrigation, though there is scarcely a summer when a temperature of 120° to 122° F. is not recorded.

As to the maximum temperature which the olive will withstand, it is hard to find a locality in the United States where a fair degree of success may not be met with.

Contrary to the often-expressed opinion that it is only successfully grown in regions adjacent to the seacoast [a] the olive thrives and produces abundantly in such hot interior localities as Biskra, Algeria; Fresno, Cal.; and Phoenix, Ariz.

At Phoenix, Ariz., maximum summer temperatures of 112° to 116° F. are matters of record, with a July mean of 90° F. The mean temperatures for the months of June, July, August, and September are 6 to 9 degrees higher than those of Catania, the warmest olive-growing station of Italy,[a] and compare quite closely throughout the year with the mean of Biskra, Algeria. (See fig. 10.)

There is near Phoenix a small but flourishing olive industry under irrigation, the trees making a rapid, healthy growth and bearing good crops of olives, yielding oil of an excellent quality. This affords proof of the high temperature which the olive will sustain when that factor alone is taken into account.

There is an area through the more wind-exposed portions of the Colorado Desert where it is possible that the hot, dry winds of the early spring prevent, as a rule, the setting of the fruit, though the few trees to be found there make a fair growth with a minimum of irrigation.

For the development of the olive fruit a rather constant number of heat units above the dormant or zero point of the olive tree is needed during the active or growing season. For convenience in transcribing the data from weather records, however, these heat units are here assumed in degrees above zero, Fahrenheit. Thus, as the mean temperature of Phoenix, Ariz., has been determined after a number of years of recorded observations to be 52° F. for the month of January, multiplying 52 by 31, the number of days, gives 1,612, representing the number of heat units for that month. Computing each month in the same manner, their sum amounts to 25,607, the number of heat units for the year.

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[a] Caruso, G. Dell' Olivo, Turin, 1883, p. 34.

Table IX shows the mean monthly and mean annual temperatures, with the sums of heat units for twelve localities of the olive-growing regions of Europe, Africa, and the United States, selected to show a range of temperatures from that at Bologna, Italy, with an annual mean of 57.16° F. and 20,895 heat units, which is slightly too cool, to that of Palm Springs, Cal., where there is probably about the extreme of heat which the olive will endure, it having an annual mean of 72.1° F. and a summation of 26,349 heat units.

TABLE IX.—*Mean temperatures and summation of temperatures, by months, at points in Algeria, Tunis, Sicily, Italy, Arizona, and California.*

Month.	Palm Springs, Cal.		Biskra, Algeria.[a]		Phoenix, Ariz.		Tucson, Ariz.		Sfax, Tunis.[b]		Catania, Sicily.[c]	
	Mean.	Summation.	Mean.	Summation.	Mean.	Summation.	Mean.	Summation.	Mean.	Summation.	Mean.	Summation.
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
January	56.20	1,742	50.5	1,565.5	52	1,612	50	1,550	51.3	1,590.3	50	1,550
February	57.50	1,610	53.0	1,584.0	56	1,568	54	1,512	54.4	1,523.2	52	1,456
March	63.96	1,983	60.5	1,875.5	60	1,860	59	1,829	59.1	1,832.1	56	1,736
April	68.62	2,059	68.0	2,040.0	67	2,010	66	1,980	63.2	1,896.0	60	1,800
May	74.19	2,300	75.0	2,325.0	75	2,325	74	2,294	68.8	2,132.8	68	2,108
June	85.06	2,552	82.0	2,460.0	85	2,550	82	2,460	72.8	2,184.0	76	2,280
July	91.55	2,838	93.2	2,889.0	90	2,790	88	2,728	78.5	2,433.5	81	2,511
August	88.23	2,735	90.0	2,790.0	89	2,759	86	2,666	79.3	2,458.3	82	2,542
September	83.73	2,512	87.5	2,625.0	83	2,490	81	2,430	78.4	2,352.0	77	2,310
October	76.48	2,371	75.0	2,325.0	71	2,201	70	2,170	72.8	2,256.0	68	2,108
November	63.93	1,918	61.0	1,830.0	61	1,830	59	1,770	61.8	1,854.0	60	1,800
December	55.88	1,729	53.0	1,643.0	52	1,612	52	1,612	54.0	1,674.0	54	1.674
Year	72.10	26,349	70.7	25,952.0	70	25,607	68	25,001	66.2	24,186.2	66	23,875

Month.	Fresno, Cal.		Los Angeles, Cal.[d]		San Diego, Cal.		Pisa, Italy.[c]		San Jose, Cal.		Bologna, Italy.[c]	
	Mean.	Summation.	Mean.	Summation.	Mean.	Summation.	Mean.	Summation.	Mean.[e]	Summation.	Mean.	Summation.
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
January	45	1,359	54.2	1,670.2	54	1,674	44	1,364	48	1,488	36	1,116
February	51	1,428	55.5	1,554.0	55	1,540	49	1,372	51	1,568	42	1,176
March	54	1,674	56.9	1,763.9	56	1,736	52	1,612	54	1,674	48	1,488
April	60	1,800	59.4	1,782.0	60	1,800	60	1,800	56	1,680	58	1,740
May	67	2,077	62.5	1,937.5	62	1,922	65	2,015	60	1,860	65	2,015
June	75	2,250	66.7	2,001.0	65	1,950	71	2,130	66	1,980	72	2,160
July	82	2,542	68.9	2,135.9	68	2,108	77	2,387	67	2,077	78	2,418
August	81	2,511	71.4	2,213.4	70	2,170	75	2,325	67	2,077	74	2,294
September	74	2,220	69.5	2,085.0	66	1,980	72	2,160	65	1,950	69	2,070
October	64	1,984	64.7	2,005.7	64	1,984	62	1,982	60	1,860	58	1,798
November	55	1,650	60.4	1,812.0	59	1,770	52	1,560	54	1,620	46	1,380
December	46	1,426	56.5	1,751.5	56	1,736	50	1,550	50	1,550	40	1,240
Year	63	22,921	62.3	22,712.1	61	22,370	60.75	22,257	58	21,384	57.16	20,895

[a] From Bulletin 53, Bureau of Plant Industry, U. S. Dept. of Agriculture, p. 64.

[b] From Bulletin 125, Bureau of Plant Industry, U. S. Dept. of Agriculture, p. 14.

[c] From "The Olive, Its Culture in Theory and Practice," by A. T. Marvin, San Francisco, 1888.

[d] Computed from data furnished by Mr. A. B. Wallaber, United States Weather Bureau, Los Angeles, Cal.

[e] Mean temperatures from "Climatology of the United States," Bulletin "Q", Weather Bureau, U. S. Dept. of Agriculture.

Caruso [a] states that the olive sap begins to stir at a temperature of 10.50° to 11° C. (which is equivalent to 51° to 52° F.) and flowers at 18° to 19° C. (equivalent to 64.4° to 66.2° F.). According to this author, we must regard the zero point of the olive as about 51° to 52° F., but the temperature figures in Table IX indicate that for such localities as Palm Springs and Los Angeles in California and Phoenix and Tucson in Arizona the zero point must be somewhat higher, probably 55° to 56° F.

To ripen the fruit within a period of safety from autumn frosts, there must be a sum of about 16,400 heat units within six or seven months from the starting of vegetation. Allowing seven months this would be equivalent to about 16,400 units from, say, the middle of March. In order to correlate this seasonal estimate with the summation of average annual heat units, as shown in Table IX, we will add to the above sum the number of heat units from January 1 to March 15 for Pisa, Italy, a typical olive locality, and we have a summation of 20,070 units, which would throw the olive ripening at Pisa to about November 20.

Hidalgo Tablada [b] gives the temperature for the flowering of the olive at 19° C. (66.2° F.) and states that at Seville this is reached about May 1. From that statement, the accumulation of 3,978 units C. (12,376 F., allowing one hundred and sixty-three days) is sufficient to mature the fruit, which will be accomplished early in October, after a growing season of 27.3° C. (81.14° F.) mean temperature. These dates of seasonal activity of the olive can be regarded only as approximations, there being variations due to localities as well as to varieties of fruit.

Data regarding the olive in relation to climate in the United States are rather meager, but what we have coincide in a very interesting way with the European observations.

Figure 10 is a graphical showing of the data of Table IX, summing up the heat units in columns for each locality, the monthly summations being carried between the heavy black lines across the chart. The heavy dotted horizontal lines show approximately the seasonal activity of the olive as it relates to these summations.

The phenological records for the olive at Phoenix, Ariz.,[c] for the year 1907–8 show the average date of full bloom of the olive to be about May 1, at mean temperatures of 66° to 71° F., shown by line *C*, figure 10.

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[a] Caruso, G. Dell' Olivo, Turin, 1883, p. 34.

[b] Hidalgo Tablada, José de. Tratado del Cultivo del Olivo en España y Modo de Mejorarlo, Madrid, 1899, p. 74.

[c] See the phenological records for Phoenix, Ariz., for December, 1907 and 1908, in the Arizona section of the Climatological Service of the Weather Bureau, U. S. Dept. of Agriculture.

The olive harvest is noted as beginning from October 8 to 10 and as completed during the latter part of December. The growing period from flower to earliest ripe fruit averages one hundred and sixty-three days at a mean temperature of 81.6° F., giving a summation of 13,314 units, which corresponds very closely with the figures of Caruso and Tablada. Adding the means, 7,050 units from January 1 to May 1, we have a total of 20,364 units.

For the full maturing of the crop of medium varieties, 24,000 to 25,000 units will be needed at this station, while late-maturing sorts will not ripen till well into the winter. Referring to the diagram (fig. 10) the line *D* indicates 20,364 units, which occur early in October for Phoenix, late in November for Los Angeles and Fresno, and barely within the year at Bologna, Italy. Caruso states that the latter place is too cool for the olive, on account of the frosts of December and January, but that the fruit matures in sunny localities on the hillsides not far from the town. In localities having low summer means but with little or no frost in the winter months, such as San Jose and Santa Barbara, Cal., where the requisite number of heat units for the first ripening of the fruits will barely be accumulated by the end of December, the olives may remain on the trees throughout the succeeding winter months. Where the summation of about 21,000 degrees can not be reached before such low autumn temperatures prevail as will injure the fruit, olive growing should not be undertaken.

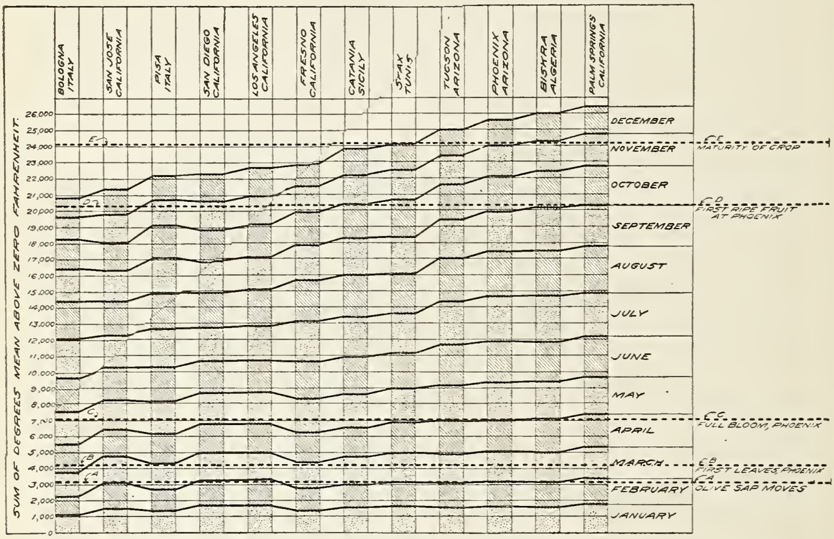

FIG. 10.—Diagram showing the monthly means and summation of heat units of places in the olive-growing regions, illustrating the seasonal activity and heat requirements of the olive, arranged from Table IX.

AREA LIMITED BY RAINFALL.

Taking up the consideration of rainfall, the industry must be considered from a different standpoint from that in which olive growing has been viewed in this country in the past. The usual planting distance has been from 20 to 24 feet. With abundant water the trees might prosper and produce remunerative crops with this area to draw from. When dependent upon local rainfall they have shown signs of failure.

In the valuable pamphlet on olive culture entitled "Investigation Made by the State Board of Horticulture of the California Olive Industry, Report to Governor Gage," 1900, page 29, is found a very significant discussion of the water problem by the Hon. Frank A. Kimball, the substance of which is as follows: Olive trees set at the ordinary orchard distance in this region, usually about 116 trees to the acre, gave during their earlier years very excellent results without irrigation. The growth was vigorous and the fruit large and fine.

Mr. Kimball gives a graphic account of their condition a few years later, as follows:

> The trees on becoming large required the necessary moisture to develop their growth, which had now assumed immense proportions. The soil could not furnish the requirements of the trees, and in the summer they lost the larger portion of their leaves. They remained in this semidormant condition until the rainy season set in or moisture from the soil began to rise. Most of the fruit dropped, and what did not fall did not attain a size suitable for picking. This condition of affairs continued until the growers resolved to apply water. After a season or more of demonstration they found irrigation to be one of the essential means through which a crop of fruit can be assured.
>
> The reason why we do not get olives is, the trees are starved, if want of water can be called starvation. For lack of water the soil can not furnish the material from which the olive is made.

The idea that the olive trees need a certain minimum volume of water for the performance of their physiological work is a fundamental one, but it does not seem to have occurred to these growers that by reducing the number of trees to the acre, thereby giving to each tree a sufficient area to afford the needed moisture, the same results might be secured as by irrigation. The olive has shown its ability to send out a root system that will secure the needed moisture from the larger area of soil and maintain a high productiveness. This has been shown by Mr. T. H. Kearney's study of the dry-land culture of the olive in Tunis, now accessible in Bulletin 125 of the Bureau of Plant Industry. From this publication we learn that a great olive-oil industry is carried on in Africa on lands receiving normally only from 9.3 to 15 inches of rainfall annually, while several good crops were produced during a period of seven years when the rainfall averaged only 6 inches, according to the French records.

The secret of this lies in wide planting, not more than 11 trees to the acre, and in clean cultivation, keeping the soil in a condition to receive every drop of rainfall and to conserve it to the utmost, the varieties used, chiefly Chemlali, being especially adapted to such conditions and affording a high percentage of oil.

The examples presented in this paper are those of the endurance of extremes of drought and neglect by varieties of the olive commonly grown in the south of Europe under conditions of sufficient, if not abundant, moisture. Their growth as trees in these arid situations in Arizona and California, interesting and suggestive as it is, would not warrant their maintenance as a commercial oil-producing enterprise. But the Chemlali and other varieties of the olive are profitably grown for oil production in the north of Africa without irrigation, and under conditions of soil and climate fairly comparable with those endured by the Arizona groves herein described. Whether the Chemlali variety will make the profitable growth in Arizona, California, and other sections of the Southwest that it has in Tunis can only be determined by careful experimentation.

The possibility that large areas of land within the proper temperature limits and having an ideal soil for the olive, yet without the rainfall or irrigation water necessary for ordinary crops, may be utilized for an olive-oil industry makes it worth while to institute experiments of sufficient extent to thoroughly test the matter. Plantings of more than an experimental character are not warranted by the present extent of our information, and the production of pickling olives is not contemplated.

In each of the instances cited where olive trees have remained alive and growing in spite of the failure of water it is necessary to remember that the plantation was established under irrigation. Likewise, in Tunis the truncheons by which the orchards are propagated are carefully watered by a supply carried from wells until sufficiently rooted to maintain themselves, three waterings usually being sufficient during the first summer. In making selections of tracts for olive culture over the drier areas indicated in Texas, Arizona, and California it must be a further condition of success that a small supply of water from some source can be assured to establish the young trees, after which a local rainfall of 7 to 12 or 15 inches annually may be expected to support the plantation and enable it to produce fair yields of fruit—perhaps enough to render dry-land olive culture profitable on a commercial scale.

SUMMARY.

In several localities in southern California and Arizona olive groves have been planted along with apricots, figs, grapes, and some other fruits. The irrigation projects under which these plantings were made subsequently failed, leaving the fruit trees without any water other than the rainfall.

The local rainfall of 3½ to 8 or 10 inches annually has proved insufficient to maintain life in any of these plants except the olive, which has been found in many instances green and flourishing after six or eight years of abandonment and lack of irrigation.

Under these conditions the olive has shown the characteristics of a desert plant, competing with the mesquite, cat's-claw, and greasewood in their own territory. The plantations which have been studied are the Bogart-Degolia grove near Casa Grande, Ariz., a grove near Florence, Ariz., and "Las Palmas" trees in the olive belt northeast of Phoenix, localities having a mean annual rainfall of 7 to 9 inches; and in California, the Pope olive grove near Palm Springs, in the upper end of the Colorado Desert, where, with an annual average rainfall of only 3½ inches, 20 acres of olives have survived six years without irrigation and are still growing.

The soils of the localities are sandy and gravelly clays derived from the disintegration of the soft granitic rocks of the adjacent mountains. They are low in organic matter, but fairly rich in available phosphoric acid and potash. The soil at Palm Springs is a nearly pure granitic sand and gravel, very low in silt, clay, and humus, but showing by analysis percentages of potash and phosphoric acid equal to the better agricultural soils of the Mississippi Valley.

A study of the olive trees growing under these conditions has shown that unlike the mesquite and some other desert trees they do not survive by sending roots down to subterranean supplies of moisture, but develop instead a very elaborate system of roots occupying the soil at from 2 or 3 to 18 inches in depth and adapted to gathering moisture from the lightest rainfall.

The remarkable drought resistance of the olive is made possible (1) by the power these trees possess of extending their roots so as to gather moisture from a large area; (2) by their habit of growth in forming low spreading tops which protect the trunk and main branches from the burning heat of the sun; and (3) by the character of their leaves, which are constructed in a manner calculated to check evaporation and conserve the moisture obtained by the roots.

The plantations studied were made according to irrigation standards and contained originally from 75 to 114 trees to the acre. These plantings have proved too thick for successful growth without irrigation.

The varieties used in these orchards are the ones commonly grown under conditions of sufficient rainfall in France and Italy or with an abundance of irrigation in California.

The publication in 1908 of Bulletin 125 of the Bureau of Plant Industry, entitled "Dry-Land Olive Culture in Northern Africa," by Mr. Thomas H. Kearney, has brought to our attention the existence of a great oil-olive industry many centuries old, in the north of Africa, dependent on an average annual rainfall of 9.3 inches. The principal varieties grown are probably of local origin, adapted to these conditions through years of selection.

Very wide planting allows a great spread of roots for moisture gathering, while a system of clean cultivation and dust-mulch forming in vogue in that country before it was occupied by Europeans conserves to the utmost the meager rainfall.

The most drought resistant of these varieties, the Chemlali, has been imported by the Bureau of Plant Industry, and is being tested at a number of localities in the Southwestern States.

In view of the remarkable drought resistance shown by European olive varieties accustomed to abundant moisture, as shown in this bulletin, it is believed that with the planting of this desert-bred variety from Africa and the adaptation to our conditions of the Tunisian methods of planting and culture, large areas of land in the Southwestern States possessing a suitable soil and climate but now undeveloped from lack of irrigation water are adapted to produce olive oil.

Trial plantations are now being made at various points in this region to determine whether such dry-land olive culture will prove profitable on a commercial scale under American conditions.

APPENDIX.

ANATOMICAL STRUCTURE OF THE OLIVE (OLEA EUROPEA).[a]

By Dr. Theo. Holm.

ROOT STRUCTURE OF THE OLIVE.

Characteristic of the root structure of the genus Olea is the presence of stereome on the inner face of the pericambium and the prevalence of cambial cell divisions on the inner face of the leptome. Otherwise, the arrangement and development of the various tissues is not different from that of many other dicotyledons.

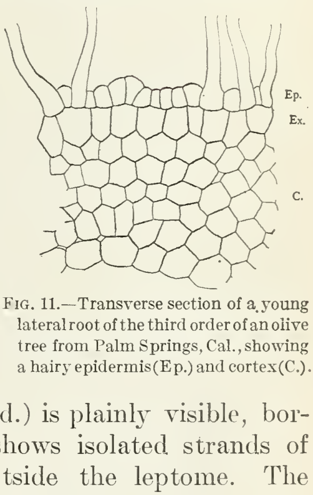

Fig. 11.—Transverse section of a young lateral root of the third order of an olive tree from Palm Springs, Cal., showing a hairy epidermis (Ep.) and cortex (C.).

The structure is as follows: In the young lateral roots of the third order (figs. 11 and 12) the epidermis (Ep.) is very hairy and covers an exodermis (Ex.) of thin-walled cells in a single layer; this exodermis is not contractile. The cortex (C.) is compact and thin walled; it consists of eight layers, more or less filled with starch; a thin-walled endodermis (End.) is plainly visible, bordering on the pericambium (P.) which shows isolated strands of stereome (St.) outside the leptome. The stele is tetrarch, there being four strands of leptome (L.) alternating with four rays of hadrome (H.), which extend to the center of the stele. Increase in thickness begins even in these thin roots, since cambial (Camb.) divisions are noticeable on the inner face of the leptome, although the increase does not extend beyond the formation of these few layers.

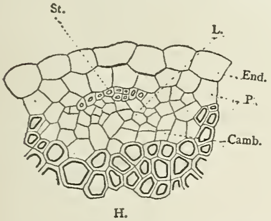

Fig. 12.—Inner portion of the same transverse section of the olive root shown in figure 11. (× 210.)

In lateral roots of the first or second order, on the other hand, the increase in thickness attains much larger dimensions, due to the activity of the pericambium in developing phellogen (Ph.) and cork (Co.) (fig. 13), besides a secondary cortex (C*) (fig. 14), to say nothing of the continued cambial cell divisions on the inner face of the leptome, as observed already in the much thinner lateral roots. The result of these various increases (fig. 14) is the development of a broad zone of cork, the development of a secondary cortex (C*), the development of a closed sheath of pericambial stereome (St.), and finally from the cambial strata the development of secondary leptome and hadrome (L. and H.) with rays of parenchyma (P.).

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[a] This description of the anatomy of olive roots, leaves, and stems, with ten illustrations, was prepared at the writer's request by Dr. Theo. Holm, of Brookland, D. C., from material collected from several California groves.

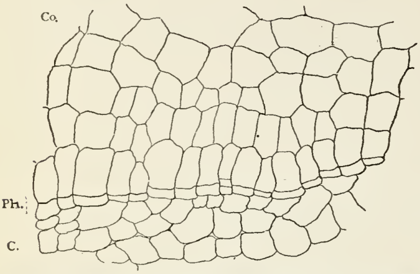

FIG. 13.—Transverse section of a lateral root of the first or second order of an olive tree, showing the development of phellogen (Ph.) and cork (Co.). (× 120.)

The diagram (fig. 15) shows the arrangement of all these tissues except the epidermis and the exodermis, which have, of course, been thrown off before this stage is reached. The center of the root possesses remnants of the primitive root stele, from which rays of parenchyma extend toward the secondary cortex (C*). The root of the genus Olea shows the arrangement of the several tissues in a remarkably regular way, and the presence of pericambial stereome is interesting.

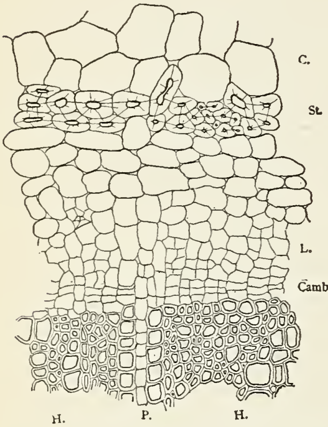

FIG. 14.—The same transverse section shown in figure 13 of the root of an olive tree, showing the development of a secondary cortex (C*) and parenchyma (P.) rays from the cambial (Camb.) strata. (× 120.)

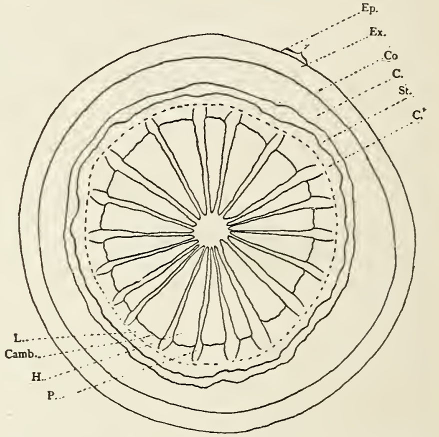

FIG. 15.—Diagram of the root of an olive tree, showing the general arrangement of tissues described in figures 11 to 14, inclusive. (× 22½.)

LEAF AND STEM STRUCTURE OF THE OLIVE.

The structure of the olive leaf is that of a xerophyte; in other words, it shows in a high degree peculiarities of structure that characterize most woody plants that grow in situations where both air and soil normally contain a relatively small amount of moisture. On the upper surface of the leaf the cuticle and outer walls of the epidermis cells are greatly thickened, stomata are absent, and shield-shaped hairs are scattered over the surface. On the lower face the outer walls of the epidermis cells are very thick (though less so than on the upper surface), the stomata are placed at the bottom of narrow pits, and shield-shaped hairs form a dense continuous covering. The interior, chlorophyll-bearing tissue (chlorenchyma) consists of three or four very compact layers of palisade cells (i. e., narrow cells, elongated at right angles to the epidermis) beneath the upper epidermis, and between the palisades and the lower epidermis many layers of so-called pneumatic tissue, the cells of which are very irregular in shape, not much longer than wide, and inclose numerous air spaces. Prosenchymatic cells with very thick walls (the stereome), either singly or in groups, are scattered through the mesophyll and occur here and there directly beneath the epidermis, as well as in several continuous layers adjoining the midrib. Between the midrib and the sheath of stereome there is no chlorenchyma, but extending to the epidermis on both sides are several layers of collenchyma, of which the cells contain no chlorophyll and have their walls greatly thickened, especially at the angles.

Of the foregoing characters, those which may be pointed out as especially xerophytic are: Thickness of the cuticle and outer cell walls of the epidermis, absence of stomata on the upper surface and their situation in pits on the lower face, and the dense covering of flat, shield-shaped hairs on the lower face. These characters are supposed to be especially useful to plants that inhabit dry climates or that grow in soils from which their roots obtain moisture with difficulty, by protecting the leaves from excessive loss of water through transpiration. The development of the chlorenchyma beneath the upper face of the leaf into several layers of compact palisade tissue is also characteristic of many xerophytes.

In leaves of the olive developed in the shade or in a moist atmosphere, the cell walls of the epidermis are much thinner, the stomata are level with the surface instead of being situated in pits, and the midrib is embedded in chlorenchyma, with a much smaller development of collenchyma.

Leaves and young twigs of olive trees were collected in abandoned orchards at Phoenix, Ariz., and at Palm Springs, Cal. In the former case the tree had been without irrigation for six years and in the latter case seven years. Since in both cases the ground water was out of reach of the roots and since the average yearly rainfall in Phoenix is but 8.11 inches and at Palm Springs only 3.5 inches, it is evident that these leaves were produced under extremely arid conditions. In fact, the conditions at Palm Springs probably represent the extreme of drought that the olive tree can endure. In both cases the varieties were not identified. For purposes of comparison, similar material of the Mission olive, the variety most widely grown in California, was obtained at Niles, Cal., where the trees are irrigated at least once during the season and where the average yearly rainfall is 14.8 inches, with a low evaporation due to the cool summer climate. The leaf and stem structure of the last, which may be regarded as typical of *Olea europea* in the western United States, is as follows:

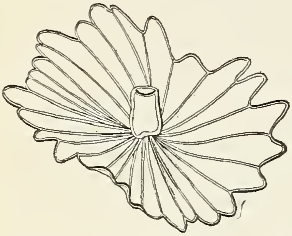

Fig. 16.—One of the peltate hairs from the surface of an olive leaf. (× 150.)

On the upper (ventral) face the cuticle is smooth and thick; the lateral walls of the epidermis cells, viewed superficially, are straight and very much thickened; stomata are wanting and peltate hairs (fig. 16) are scattered over the surface. On the lower (dorsal) face the cuticle is similar; the radial walls of the epidermis cells are almost straight, but not so much thickened as on the upper face; the numerous stomata (fig. 17) are sunken, with narrow and not very deep air chambers, and are surrounded by a variable number of undifferentiated epidermis cells; peltate hairs (fig. 16) are abundant, forming a continuous covering over the blade. The outer walls of the epidermis cells (figs. 17 and 18) are very thick on both faces of the leaf and show an increase in thickening very plainly. On the dorsal face they show many deepenings caused by the irregular thickening of the cell wall (fig. 17). The inner and radial cell walls of the epidermis are rather thin as compared with the outer walls. The unicellular stalks of the large shield-shaped hairs are located in circular cavities, the peltate part of the hair, which consists of numerous radially arranged cells, resting upon the outer wall of the epidermis.

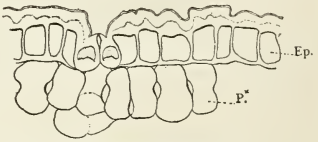

Fig. 17.—A sunken stoma and the uneven dorsal surface of an olive leaf.

The chlorenchyma is differentiated into palisade and pneumatic tissues. The former (fig. 18) consists of three compact layers of very high cells containing chlorophyll and small needle-shaped crystals of calcium oxalate. It extends from the margins of the blade to the midrib, where it ceases, being broken by the hypodermal collenchyma. On the dorsal side of the blade there is a thick pneumatic tissue of many layers. The cells which, like those of the palisade, contain numerous needle-shaped crystals of calcium oxalate, are of a very irregular shape and the intercellular spaces are very wide (fig. 19). The pneumatic tissue, like the palisade tissue, is broken at the midrib by hypodermal collenchyma.

The stereome is thick walled and very unequally distributed. It occurs hypodermally (immediately beneath the epidermis) as single cells or a few cells together on both faces of the blade (fig. 18), as scattered cells in the collenchyma (Pl. V, fig. 1), and as a pericycle of several continuous layers in the midrib (Pl. V, fig. 1). It is characteristic of the genus Olea that the stereome cells traverse the pneumatic tissue in all directions (fig. 19). The pericylic stereome is thick walled only on the hadrome side of the midrib; on the leptome side it is thin walled with a very few thick-walled cells interspersed. The collenchyma (Pl. V, fig. 1) is hypodermal above and below the midrib and extends to the pericycle; it is generally thick walled, especially near the epidermis.

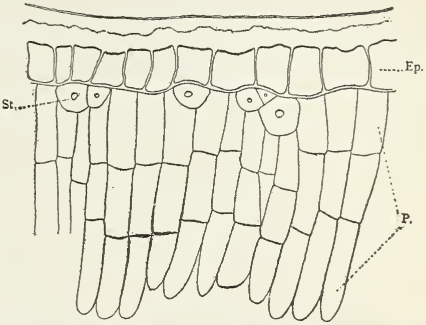

FIG. 18.—Ventral face of an olive leaf, showing the thickened walls of epidermal cells and palisade cells. (× 150.)

The mestome strands are, with the exception of the midrib (Pl. V, fig. 1), embedded in the chlorenchyma, and all the lateral strands are surrounded by thin-walled parenchyma sheaths, sometimes with a few adjoining stereome cells. The midrib has no parenchyma sheath and no endodermis, but, as previously described, it is surrounded by a thick sheath of stereome. All the mestome strands are collateral. The leptome forms an arch underneath the shorter but broader arch of hadrome. In the latter, each double row of vessels is separated from the next by a single row of parenchyma cells (parenchymatic ray).

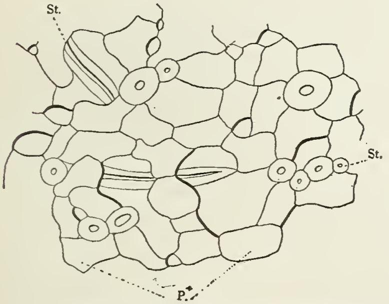

FIG. 19.—Pneumatic tissue of the dorsal side of a blade traversed by stereome cells. From a leaf of the Mission olive. (× 150.)

The petiole, examined at the characteristic point (where the mestome strands enter the leaf blade), shows a hemicylindric outline in cross section. It is covered with shield-shaped hairs, as is the blade, and the outer walls of the epidermis cells are extremely thick. The cortex is a solid mass of collenchymatic tissue and contains an arch-shaped collateral mestome strand in the center. This mestome strand has no support of stereome in the stricter sense of the word, but is simply surrounded by a small collenchymatic tissue. Leptome and hadrome show the same structure as in the midrib of the blade.

The arrangement of the tissues of the stem is shown in Plate V, figure 2. The cross section of the young twig is quadrangular and minutely four winged. The thin, smooth cuticle covers an epidermis with hairs similar to those of the leaf, and the outer cell walls are very thick; inside the epidermis are about twelve layers of cortical parenchyma, collenchymatic in the peripheral layers but more thin walled around the stele. Phellogen appears in the outermost layer of the cortex and soon develops several layers of cork, of which about three develop during the first summer. (Fig. 20.)

There is no endodermis, but a stereomatic and very thick-walled pericycle surrounds the stele. This pericycle, however, is not continuous, but consists of many strands of stereome separated by a few parenchymatic cells. The leptome presents a circular zone bordering on the pericycle, and is separated by cambium from the hadrome. The vessels (the scalariform ones especially) are thick walled and separated from each other by parenchymatic rays, each of a single row of rather thin-walled cells. The cells of the pith (which is solid) have thick porous walls and contain much starch.

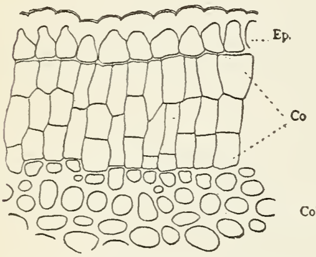

FIG. 20.—Development of cork layers in the cortex of an olive stem. (× 150.)

As compared with the preceding (the Mission variety from Niles, Cal.), the unknown variety of olive of which material was collected in the orchard at Phoenix, Ariz., is noteworthy for the extremely thick-walled epidermis on both faces of the leaf; thick-walled collenchyma extending from the epidermis to the pericycle of the midrib; more stereome in the pericycle; palisade and pneumatic tissues more compact but containing less stereome. In the petiole all the tissues are extremely thick walled. Cork develops very early in the stem, since even in the apical internode there are seven layers. The epidermis of the apical internode is extremely thick walled.

The two unidentified varieties collected in the abandoned orchard at Palm Springs appear to be identical in anatomical structure. From the variety growing at Phoenix they differ only in the much narrower midrib.

To summarize: The leaf and stem structure of the olive are such as to protect it admirably against excessive loss of water by transpiration and hence adapt it to growing in very dry soils and climates. The scanty evidence here presented would seem to indicate that the considerable difference in aridity represented by the two environments at Niles (where the average yearly rainfall is 14.8 inches, where moisture-laden winds blow in from the ocean, and where occasional irrigation is given) and of Palm Springs (where the average yearly rainfall is only 3.5 inches, where the air is excessively dry, and where the trees had received no irrigation for seven years) has a distinct, though comparatively slight, effect upon the anatomical structure of this plant, for even at Niles the olive exhibits in a high degree the characteristics of a xerophytic plant.

PLATES.

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DESCRIPTION OF PLATES.

Plate I. Fig. 1.—One of the larger olive trees on the Bogart-Degolia plantation near Casa Grande, Ariz. Fig. 2.—Olive trees in the "Las Palmas" section, near Phoenix, Ariz., after six years of neglect and lack of water.

Plate II. Fig. 1.—View in the Florence, Ariz., olive grove, about 16 years old, which has had no irrigation for the past six years. At the left, dead apricot and almond trees of the same age; at the right, olive trees in vigorous condition. Fig. 2.—Interior view in the grove shown in figure 1, showing a fine growth but thinner foliage than in the outer row shown in figure 1, due to the crowding of the trees.

Plate III. Fig. 1.—View in the Pope olive plantation, near Palm Springs, Cal., after six years of neglect. Mean annual rainfall only 3½ inches. Fig. 2.—One of the larger trees, 8 feet high, in the Pope olive plantation, showing the low habit of growth and the protection of the trunk and main branches from heat by a canopy of foliage.

Plate IV. Fig. 1.—Characteristic burl at the base of an olive tree on the Pope olive plantation, near Palm Springs, Cal. Fig. 2.—Feeding rootlets, natural size, from 6 inches in depth, on the same plantation shown in figure 1.

Plate V. Fig. 1.—Cross section of the midrib of the leaf of Olea europea (Mission variety), showing the epidermis, palisade tissue, massively developed collenchyma, pericyclic stereome, hadrome, leptome, and pneumatic tissue. Magnified 180 times. Fig. 2.—Cross section of one of the apical internodes of the stem, showing the epidermis, hypodermal collenchyma, stereome ring, leptome, hadrome, and pith. Magnified 112 times.

Plate VI. Fig. 1.—View in a 500-acre olive plantation in southern Los Angeles County, near La Mirada, Cal., grown without irrigation. The planting distance of 20 feet each way is much too close for the full development of the trees. Fig. 2.—View in a different part of the plantation shown in figure 1, where the trees have been thinned by removing alternate diagonal rows. The conditions are consequently much improved.

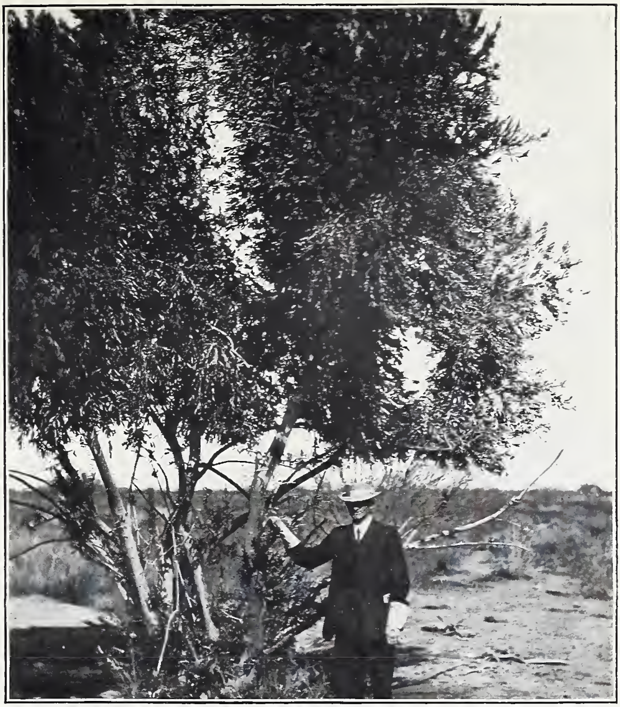

FIG. 1.—ONE OF THE LARGER OLIVE TREES ON THE BOGART-DEGOLIA PLANTATION, NEAR CASA GRANDE, ARIZ.

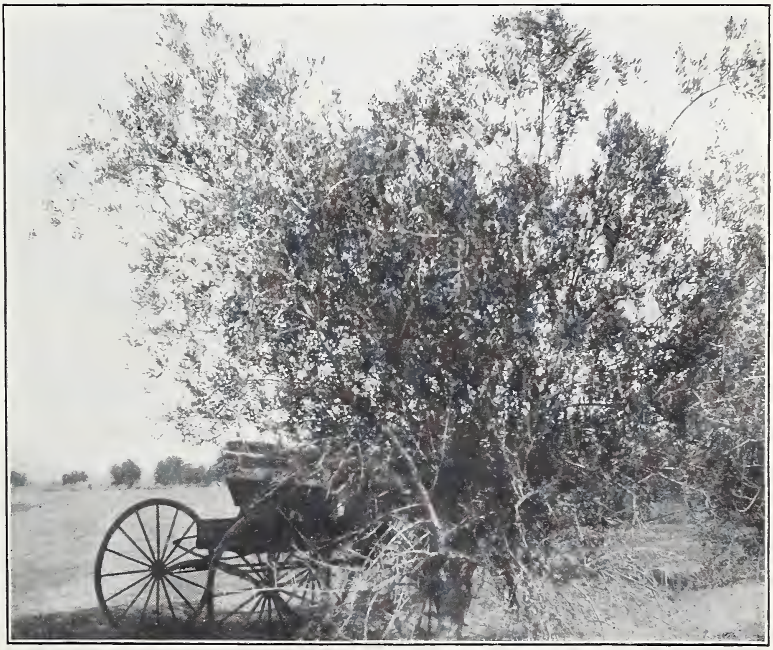

FIG. 2.—OLIVE TREE AT "LAS PALMAS," NEAR PHOENIX, ARIZ., AFTER SIX YEARS OF NEGLECT.

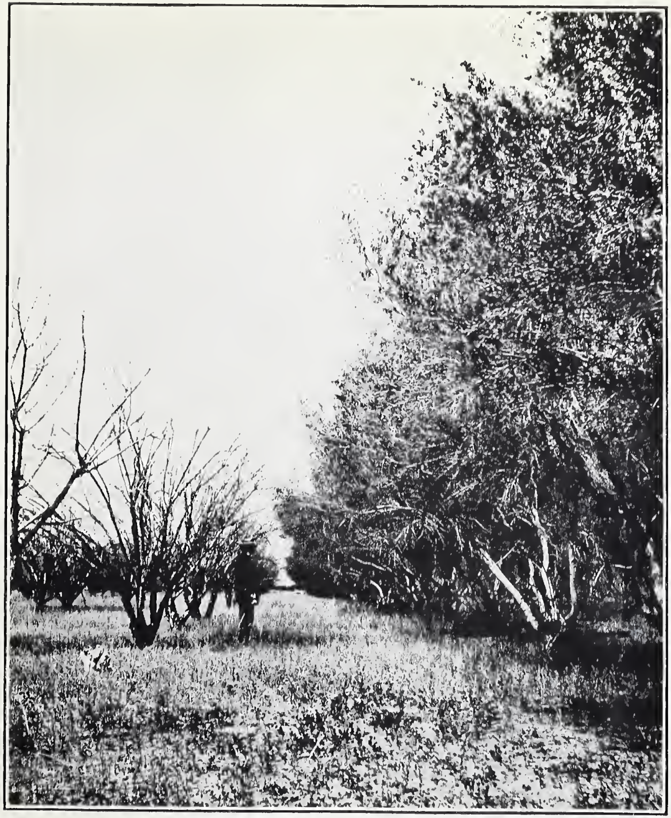

FIG. 1.—VIEW IN THE OLIVE GROVE AT FLORENCE, ARIZ., SHOWING DEAD APRICOT AND ALMOND TREES IN CONTRAST WITH FLOURISHING OLIVES AFTER SIX YEARS WITHOUT IRRIGATION.

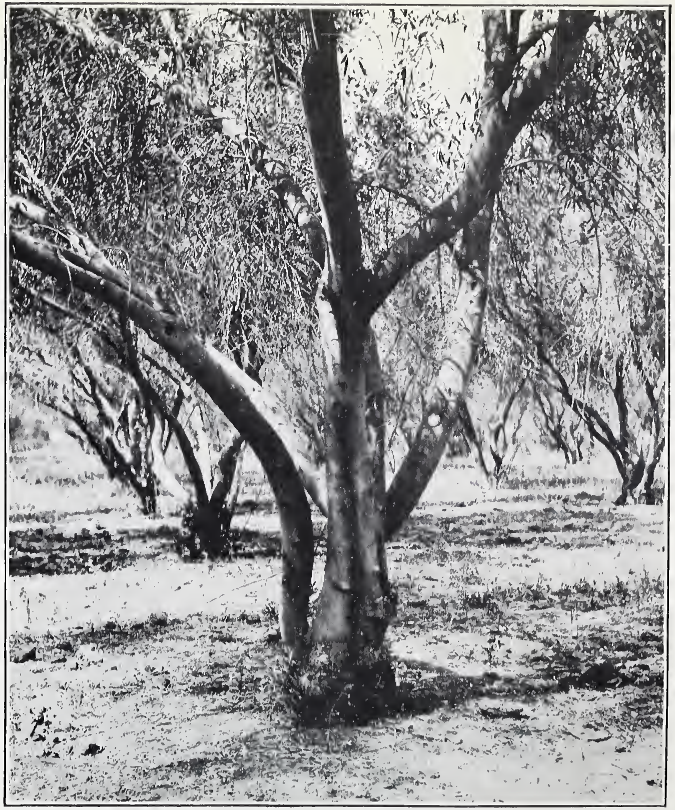

FIG. 2.—INTERIOR VIEW IN THE GROVE SHOWN IN FIGURE 1, THE FOLIAGE, ON ACCOUNT OF CROWDING, HAVING BECOME THINNER THAN THAT OF THE OUTER ROW.

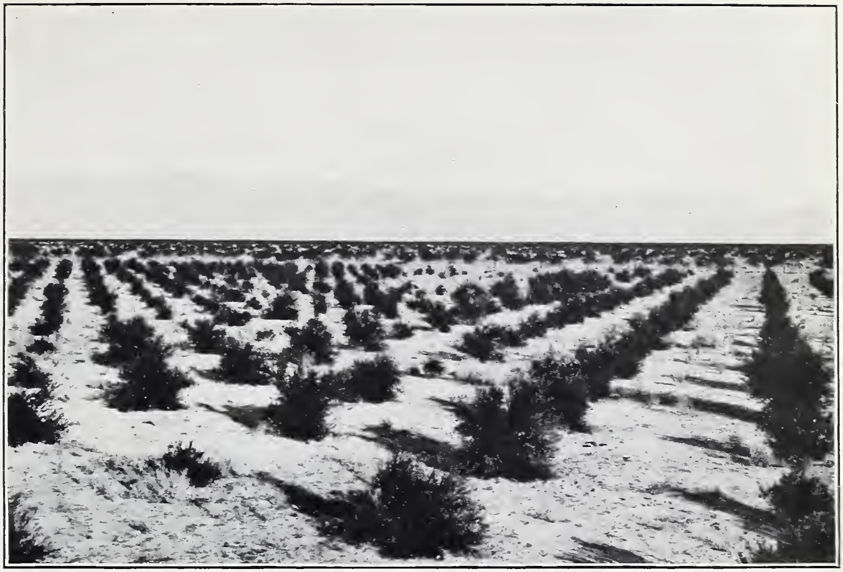

FIG. 1.—VIEW IN THE POPE OLIVE PLANTATION, NEAR PALM SPRINGS, CAL., AFTER SIX YEARS OF NEGLECT.

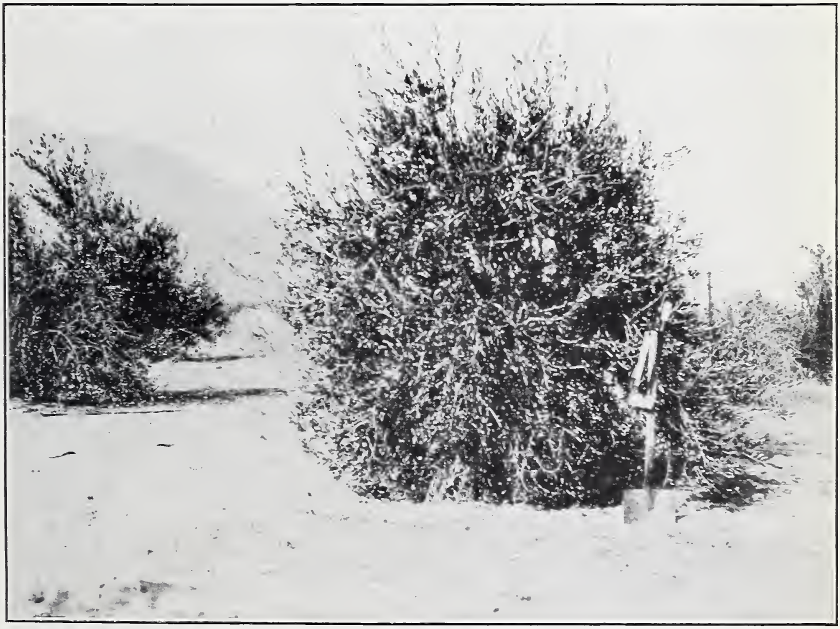

FIG. 2.—ONE OF THE LARGER TREES IN THE POPE OLIVE PLANTATION, SHOWING THE LOW HABIT OF GROWTH OF THE TREES.

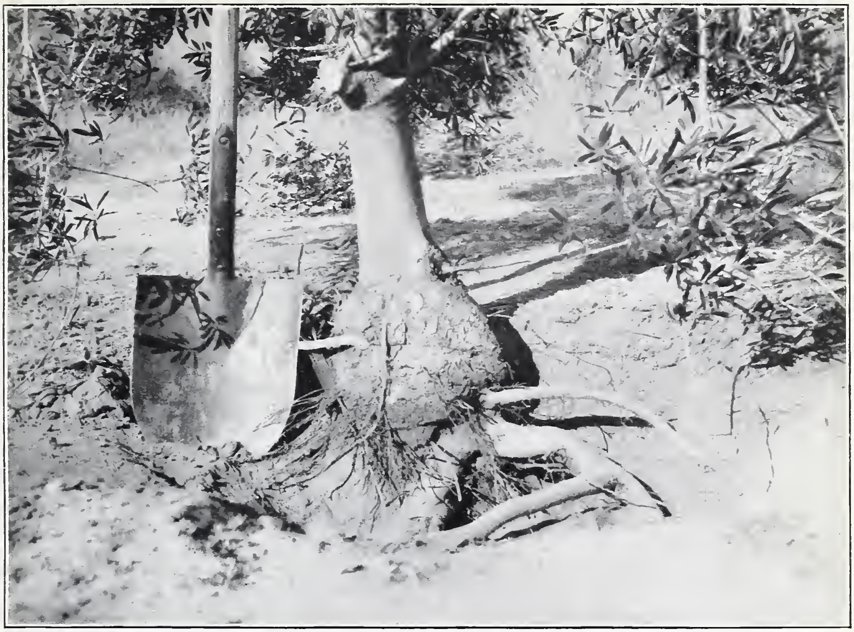

FIG. 1.—CHARACTERISTIC BURL AT THE BASE OF AN OLIVE TREE ON THE POPE PLANTATION, NEAR PALM SPRINGS, CAL.

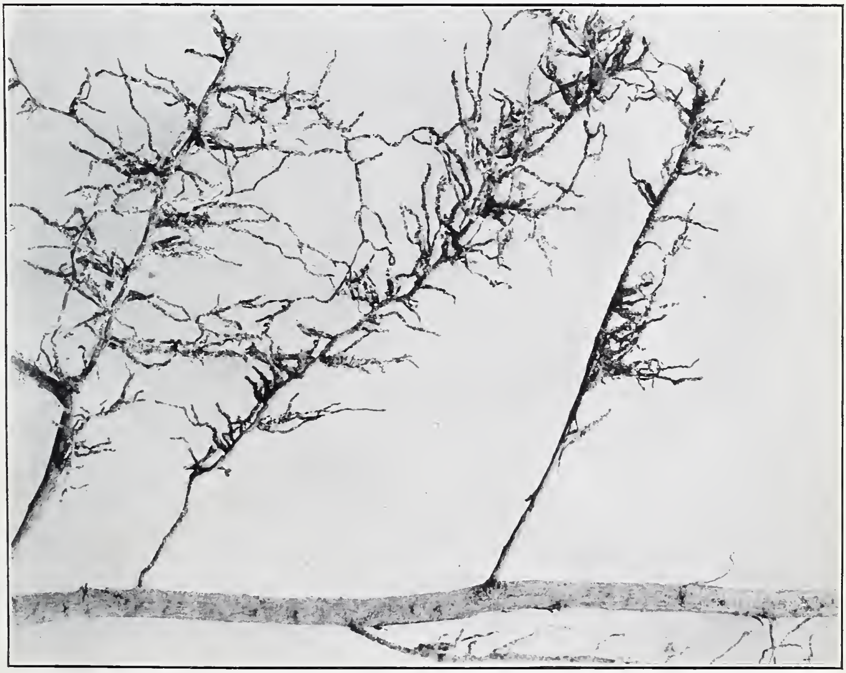

FIG. 2.—FEEDING ROOTLETS, FROM 6 INCHES IN DEPTH, ON THE POPE OLIVE PLANTATION. (NATURAL SIZE.)

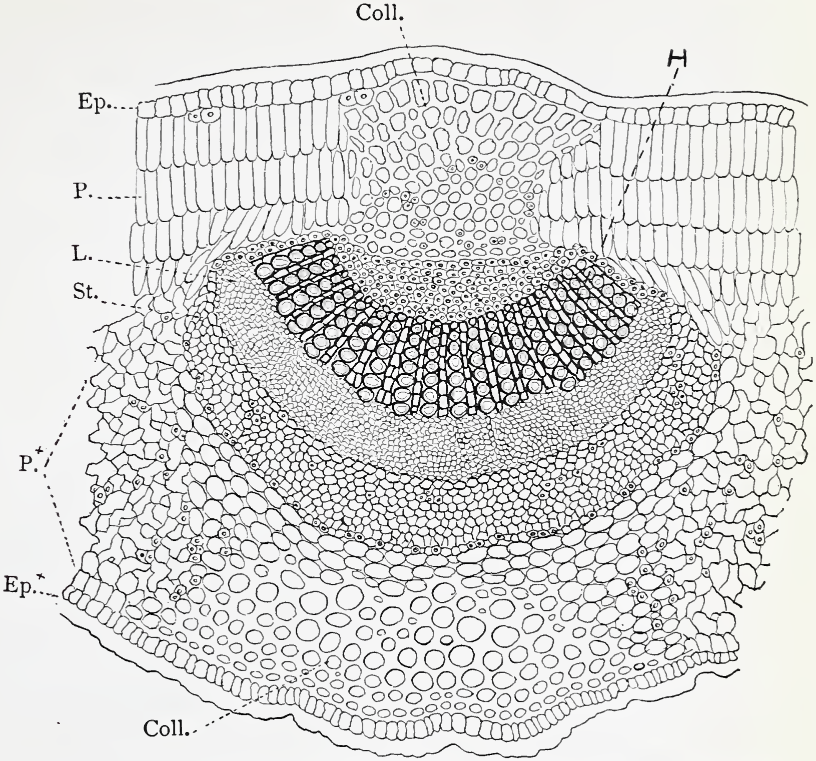

FIG. 1.—CROSS SECTION OF THE MIDRIB OF THE LEAF OF OLEA EUROPEA (MISSION VARIETY).

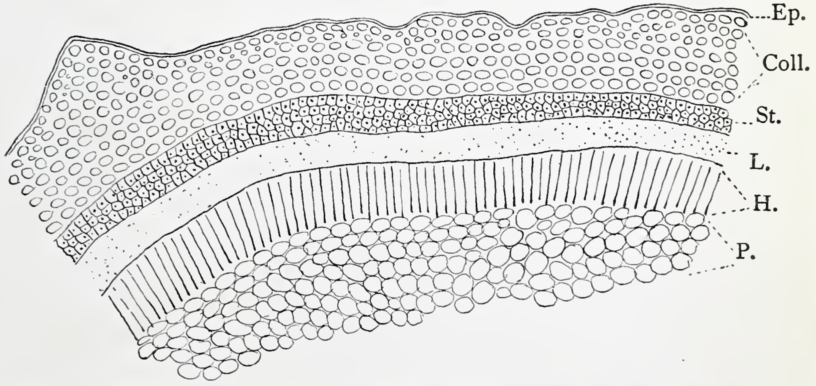

FIG. 2.—CROSS SECTION OF ONE OF THE APICAL INTERNODES OF THE STEM OF OLEA EUROPEA (MISSION VARIETY).

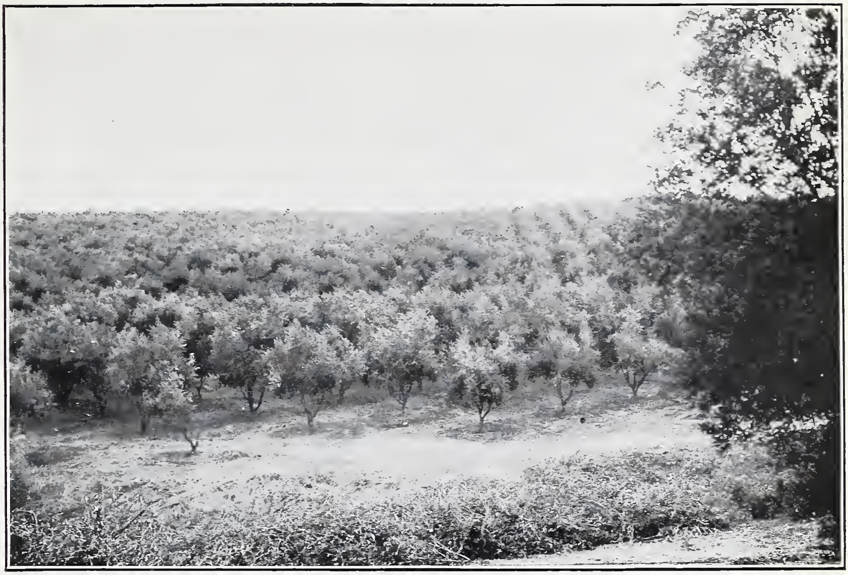

FIG. 1.—VIEW IN THE 500-ACRE OLIVE PLANTATION NEAR LA MIRADA, CAL.

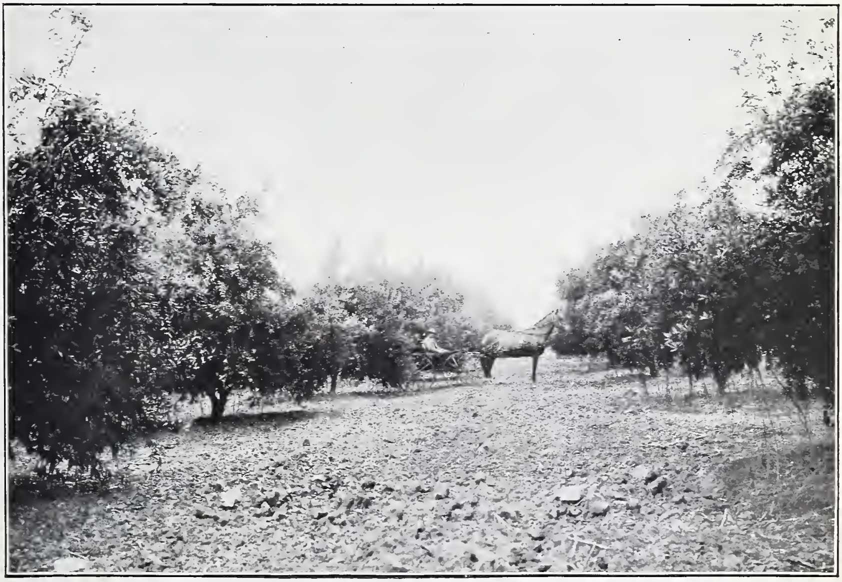

FIG. 2.—VIEW IN A DIFFERENT PART OF THE PLANTATION SHOWN IN FIGURE 1, WHERE THE TREES HAVE BEEN THINNED BY REMOVING ALTERNATE DIAGONAL ROWS.

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